THE GREAT CANTILEVER BRIDGE 1883 OVER THE NIAGARA RIVER.

The Iconographic Encyclopædia

OF THE

ARTS AND SCIENCES

Translated from the German of the

BILDER - ATLAS

(Iconographische Encyclopædie)

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THE

ICONOGRAPHIC ENCYCLOPÆDIA

CONSTRUCTIVE ARTS

BASED UPON THE GERMAN OF

DR. WILHELM FRÄNKEL AND RUDOLF HEYN
PROFESSORS AT THE ROYAL POLYTECHNIC COLLEGE OF DRESDEN

AND

AUGMENTED BY EXTENSIVE ADDITIONS EMBRACING THE MOST RECENT INVENTIONS AND THE LATEST APPLICATIONS OF THE NATURAL FORCES IN THE DOMAIN OF

BUILDING AND ENGINEERING

BY WILLIAM H. WAHL, A.M., PH.D.
SECRETARY OF THE FRANKLIN INSTITUTE, PHILADELPHIA.

ILLUSTRATED WITH 62 PLATES COMPRISING MORE THAN 930 FIGURES.

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EDITOR'S PREFACE.

IN the present volume the purpose of the authors has been to present a measurably comprehensive view of the CONSTRUCTIVE ARTS by developing as logically as possible, in their historic order, the numerous themes involved in a subject so extensive, and by calling to aid the art of illustration wherever the topic could be better elucidated therewith.

The scope of the work comprises the consideration of the materials employed by the constructor, and of the methods and processes by which these materials—assumed in this scheme to be finished and ready to the hand—are directly utilized and adapted to the requirements of man. The technology of the mining, metallurgical, and mechanical arts, by which these materials have been extracted from the earth, separated from their combinations, and fashioned into useful forms, is excluded as far as is consistent with lucidity of description. Moreover, as the volume is restricted to the practical portion of the arts of construction, with especial reference to the useful purposes they are designed to subserve, the consideration of the æsthetic element is likewise excluded except where it has been necessary to introduce it incidentally.

The subjects presented for consideration naturally fall into two general divisions—BUILDING and ENGINEERING.

Building, in the limited signification of the term—that is, the creation of artificial structures for shelter—naturally precedes, in the historical development of the subject, the more advanced theme of engineering construction. Under the general division devoted to building the practical details of the construction of dwellings and of buildings for public purposes are treated of from the standpoint of the uses they are designed to serve, in which connection consideration has been given not only to the relations of the various elements and parts of these structures, and to the division of the interior of the same into spaces and apartments in the manner best adapted to secure the greatest degree of suitability and convenience, but also to the important element of security. In these considerations the æsthetic element—which relates to what is popularly called the "architectural" style—could not be wholly excluded; but such consideration as it has received is wholly subordinated to the more important feature of utility.

The ends to be accomplished in the production of engineering works are to provide means of establishing and facilitating intercourse, partly by the creation of highways by which the natural and manufactured products of one region may rapidly and safely be transported to another; partly by administering to the commercial requirements upon which the existence, and especially the growth, of great cities depend as centres for the promotion of the industries, the arts, and sciences by the provision of works for water-supply and drainage, paved streets, means of rapid transit, etc.; and partly by contributing to the general material interests of nations and the mutual interchange of the arts of civilization.

The means of intercommunication above referred to may be provided either upon land or by water, and accordingly the construction of roadways, railways, and hydraulic works constitutes the several branches of engineering with which the present work is concerned. In close relation to the foregoing stands the art of bridge construction, which is given its full share of consideration. The bearing of the modern art of telegraphy and its congeners in facilitating intercommunication and contributing to the celerity of traffic is too important to be overlooked, and accordingly the principal facts in connection with this branch of applied science have been duly considered.

In all the divisions of the work the effort has been made to present the subjects treated of in as comprehensive a manner as possible, omitting unessential details and giving only the substantial and essential general features, in terms as concise as possible with proper regard to lucidity of description. Technical terms have been avoided as far as practicable, that the general reader may be able intelligently to read and comprehend descriptions which in strictly technical works are to him frequently rendered quite useless. The illustrations have been selected and prepared with great care, and with the view not only of aiding in the comprehension of the more technical subjects, but also of presenting in picture the appearance of many notable building and engineering structures.

While the text is based on the German of the BILDER-ATLAS, the translation from that work is confined exclusively to subjects illustrated by the thirty double-page plates. The thirty-two single-page plates have been prepared expressly for this volume at the suggestion of the Editor, who has furnished the accompanying text, in which a great variety of topics not found in the original have been considered, and which will be of especial interest to all who desire accurate information relative to recently-invented appliances and new methods in the constructive arts. This additional material, it is believed, will fairly represent the best features of recent practice.

WILLIAM H. WAHL.

PHILADELPHIA, April, 1889.

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PART I.—BUILDING.

CONSTRUCTIVE ARTS.

PART I.

BUILDING.

THE subject that will occupy our attention in the following sections relates strictly to the mechanical operations involved in carrying into effect the plans of the designer or architect; in other words, we shall concern ourselves with the strictly practical or mechanical parts of architecture, as distinguished from its æsthetic features. The latter form the subject of a separate volume, to which the reader is referred.

The mechanical operations herein embraced involve, in addition to the selection of the plan with proper reference to the ground which the building shall occupy, the preparation of foundations; the installation of appliances for the proper drainage of the building; the details of the superstructure, embracing the methods of constructing walls of natural and artificial materials (wood, stone, brick, concrete, etc.); the construction of roofs and of the gutters thereon with suitable connections to dispose promptly of the water received upon them; the proper arrangement of flues for heating and ventilation; the construction of partition-walls, floors, ceilings, and other interior details; the use of suitable methods for protecting the various portions of the building from deterioration by dampness, from destruction by fire, and from natural or special causes of decay, etc.

The proper execution of these mechanical details demands on the part of the builder an expert familiarity with every portion of the practical work involved in the construction of buildings, including, also, such knowledge of the value of materials and labor as will enable him intelligently to estimate in advance the actual cost of the intended structure.

1. Principles of Construction.

Planning.—The first task to be performed in connection with the erection of a building is to form an approximately accurate conception of its characteristics. In works of a complex nature, especially if they have features embodying novel arrangements or artistic effects, an architect is usually employed, and one of his first duties is to furnish a plan or design which shall represent as closely as possible, in specially convenient and economical modifications, the leading ideas of the projector. In the mass of buildings, however, most of the details of adjacent structures or of printed descriptions are closely imitated, and such aids leave little necessity for planning except in reference to matters about which the advice of competent contractors or constructors furnishes all necessary information.

In the planning of any building-structure the builder will be guided primarily by the uses it is intended to subserve, then by the nature and area of the available site on which it is designed to erect it; and it will be obvious that that plan will be best which, with the proper regard for the foregoing considerations, combines the highest degree of fitness and convenience with the lowest cost. In many cases, however, the æsthetic feature enters as an element of greater or less importance. But, while this should receive due consideration, the architectural design should always be subordinated to the prime conditions above noted, and it is universally held to be evidence of the correct use of the principles that should be followed in the application of architectural design when the building exhibits at a glance the purpose for which it is intended.

Substructure: Foundations.—The term "foundation" is properly restricted to that part of an edifice which is intended to serve exclusively as the basis upon which to erect the superstructure, the word being frequently applied to that portion of ground which supports the building, and also to the various artificial arrangements prepared to support the base, which latter would be more properly termed the "foundation-bed." Solidity of base is the primary consideration, and the main object is to insure the stability of the superstructure by preventing any movements of its parts after completion. As, however, nearly all soils are to some extent compressible under weight, and as works of masonry settle slightly, it would be more exact to say that the builder exerts his art to insure that this settlement may be unimportant and uniform rather than in the hope of preventing it entirely. The condition and the quality of the soil to be built upon demand primary consideration in determining the character of the foundation, and the firmness of the ground should be thoroughly tested.

Condition and Quality of Soils.—Foundations can be considered under two general classes—those constructed in a natural soil capable of bearing the weight of the intended superstructure, and those in situations where the conditions of the soil necessitate the creation of an artificial support. To determine the quality of the soil in ordinary circumstances, when excavations such as wells and culverts have not already revealed the conditions, it is only necessary to dig a pit in order to examine the strata. A bed of firm soil from 2 to 4 feet in thickness immediately below the foundation is sufficient to support any ordinary structure, even though it should be underlaid, in turn, by a much softer stratum. When a greater stability is deemed essential for important edifices, the nature of the subsoil can be ascertained by the introduction of the auger-pump, or other means of boring.

Foundations in Compact Soil.—In compact and stony earths, such as sand and gravel, foundations are dug from 4 to 6 feet in depth, in order to reach below the action of frost, and, when necessary, drains are required to carry off all surface-water. Strong gravel is considered as one of the best soils, being easily levelled, almost incompressible, and unaffected by exposure to the atmosphere. Sand has also the advantage of incompressibility, but demands special treatment on account of its want of cohesion. In proceeding with the walls it is necessary to give them a bearing greater than their own width, in order to distribute the weight over a greater surface. This increased width in the foundation-courses is styled the "spread" or "footing." When the soil is as firm as the principal constituent of the wall itself, it is not necessary to give much width to this spread. In firm earth it is usually made one and a half times the width of the wall, and in sand and ordinary soil twice that width. Clay soil, even when sufficiently firm, is affected by water, and the bed should be prepared by digging a trench to drain the ground. The foundation must also go below the frost-line, as clay soils are much affected by cold and should be protected from exposure to the weather as much as possible.

Foundations in Soft Soil.—In the second order of foundations a soft soil demands the introduction of an artificial bearing-stratum. In this case the first requirement is a trench of sufficient depth to permit the footing of the walls to reach below the action of rain and frost. The bottom of this trench can be covered with a bed of stones well rammed down and covered with concrete. Sand is also used, and is remarkably well fitted for the purpose of a foundation-bed, as it distributes the pressure both vertically and horizontally. One of the most common methods of making a foundation-bed in loose ground is by driving wooden piles into the soil and building the foundation-walls upon them. Straight-grained timbers are required for this purpose, the preferred woods being fir, beech, oak, Florida yellow pine, spruce, and hemlock. A modern substitute for wooden piles, both for economy and service, is the pile made of sand. When the soil is not very loose and wet, holes can be made in the bottom of the trench about 6 feet deep and 6 or more inches in diameter, and filled with damp sand well rammed down, which transmits the vertical pressure over a larger surface of the underlying soil than can be effected by the use of wooden piles. A bed of masonry or concrete should cover the ground above these piles, to prevent the sand being forced upward, and upon this bed the foundation-walls can be placed.

Concrete Foundations.—In many places concrete is superseding every other form of artificial foundation, because of its cheapness and convenience. Ramming of concrete, when thoroughly done, consolidates the mass five or six per cent., rendering it less porous and very materially stronger. Concrete has also proved of great utility in the erection of foundations and walls beneath water, modern ingenuity having invented a species of box in which it can be let down into the depths, where a pin drawn out by a rope reaching to the surface permits the side of the box to swing out and deposit the concrete upon the very spot where it is required. Concrete is useful in filling in cavities in rock and in bringing up uneven foundations to a level for the support of masonry. In making foundations in compressible soil it is sometimes found possible to extend excavations through it to a firmer stratum beneath, but this often involves great expense.

Foundation-walls.—In beginning the foundation-walls of a building, the spreads or footing courses, already mentioned, are of essential importance as a means of distributing the weight over an increased surface and diminishing vertical settlement. They should be securely bonded into the body of the work, and of sufficient strength to resist any cross strains to which they may be subjected. Footings of undressed rubble should always be laid in cement plaster to form a solid mass. Bricks used for courses should be of the hardest and strongest quality, and the bottom course should invariably be double. Foundation-walls, always starting below the line of frost, should be made as compact as possible. The bottom courses are frequently laid dry, and the rest in cement mortar. When composed of stone, they should never be less than 20 inches thick; and if of brick, not less than 12 inches thick. In wooden buildings a foundation-wall, when of brick, is generally 12 inches thick, and when of rubble, 18 inches or more.

Drainage.—As a general term, "drainage" is used to express the mode in which the waters of a country pass off by its streams and rivers; but when used in connection with building, it is restricted to the drains and sewers by which water is removed from cities and all works erected by builders. The system as adopted for cities and towns is usually distinguished as "sewerage"—a term used also, improperly, to express the material collected and discharged by sewers and drains. For convenience in discrimination, the material collected is now generally termed "sewage." The art of freeing land from superfluous water by artificial means has long been practised by various methods of ditching. Drains made of tiles have been used most successfully in the reclamation of wet lands, which then become more productive to tillage. A concave bottom for all kinds of drains is found to facilitate the discharge of the contents and prevent the accumulation of impurities.

Drain-pipes.—By modern improvements, drain-pipes of hard vitreous substance are introduced wherever possible, as not being susceptible of any chemical action from the sewage, and as being little affected by frost. Pipes or hollow cylinders of terra-cotta and well-burnt glazed stoneware make efficient house-drains, and are put together with great accuracy with sockets, so as to fit spigot and faucet fashion, removable tops being arranged to give access to the interior when required. Modern science has been applied extensively to improvements in drainage, and minute investigation devoted to various questions of foundation, incline, securing action of flow, and every particular of ventilation and security. Estimates of rainfall over given areas have also necessarily entered into the computation of competent supplies of drainage facilities, with careful consideration of all obstacles, both natural and artificial, which present hindrances to effectual service. In using pipes for drains, the capacity should be abundantly large for any possible flow, a bore of not less than 6 inches being advised by some authorities. Among the various drain-pipes now used, the slip-glazed clay pipe is composed of fire-clay glazed with a species of clay called "slip." Other pipes are glazed by the vapor of salt thrown into the fire during the manufacture and chemically uniting with the clay, which vitrifies under the intense heat into a glassy, impenetrable coating.

Sewers.—By ordinary usage, a sewer designates a drain constructed under the streets of a city to carry off the surface-water, and also liquid refuse matter from the houses. Large sewers accessible at the ends or from special entrance-places, termed man-holes, are made circular, elliptical, or egg-shaped, the latter shapes being preferred as permitting greater height in proportion to the capacity. A rate of fall of 1 inch in 10 feet is considered desirable, though less suffices for a main sewer. The large sewers have been built usually of brick, the smaller ones being of glazed stoneware. Cement for the composition of sewer-pipes has been objected to as not sufficiently uniform in quality and not sufficiently durable for large constructions. To secure unyielding foundations for large sewers and culverts under high embankments and in soft ground where great pressure may occur, inverted arches or beds of masonry are inserted within the walls to strengthen the structure. Beds of gravel, sand, or broken stone are also placed as foundations beneath culverts. The substitution of smaller earthenware pipes for the larger brick sewers has been found advantageous in increasing the rapidity of the flow of material, and thus decreasing the amount of foul gas produced by decomposition.

The catch-pools built at corners of the street receive the surface-water from gutters, and, leading it into the sewers, assist in flushing them. The ventilation of sewers has been much considered, and various methods of gratings in streets have been introduced, and experiments have been made in the use of ventilating shafts by means of tall lamp-posts and chimney-flues. The deodorizing of sewers has been the subject of many experiments, but on account of the great volume of material to be treated it is found impracticable to employ chemical substances for the purpose, and frequent flushing is the proper and efficient remedy.

Ventilating Pipes and Traps.—The danger consequent upon the admission of sewer-gases into dwelling-houses has been brought so forcibly to public attention of late years that preventive methods have been the subject of general and scientific consideration. Ventilating pipes carried above the roofs of buildings have been largely relied upon for sanitary effects, and traps have been connected with waste-pipes to prevent the intrusion of the gas. Various devices make special claims on the score of cleanliness, effectiveness of sealing quality, and protection against siphoning, the latter appearing to be the most serious obstacle to the effective operation of these traps in general. Security against evaporation and saturation by the absorption of gases from beneath has been a special matter for consideration. Traps of glass with metal covers have been designed expressly for connection with washbasins, bathtubs, sinks, etc., with the object of preventing any entrance of gas from below by the interposition of a body of water or other fluid, or by mechanical means.

Superstructure: Object of Construction.—The nature of the object to be attained deeply affects the selection of material and modes of construction. The diversity of purposes is increased by differences in economic conditions and surrounding circumstances. In the United States, fluctuations in fortune have been so numerous and frequent that with many men the operation of constructing at one period of their lives a dwelling intended for personal use would have differed widely from an undertaking having the same object in view commenced at another stage of their career. Differences in locality or latitude, and relative scarcity or abundance of particular kinds of material or of experts in various branches of the building trades, may also materially affect either the cost or the practicability of completing a structure within a given period. Considerations relating to such matters should receive due attention, and incite the formation of definite ideas, in advance of the commencement of construction.

Stability of Walls.—A leading purpose in the construction of walls is to insure their stability—at least, during the period of their probable usefulness. In the United States, the process of tearing down one set of buildings that they may furnish the site for improved structures has been conducted on so extensive a scale, that stability, in the sense of securing the greatest possible prolongation of usefulness, has frequently not received the degree of attention devoted to it in many other countries; on the other hand, some of the latest structures of extensive proportions represent extraordinary efforts to insure stability. As buildings are commonly constructed, the walls are usually much the most durable portions of the structure, unless there has been exceptionally bad workmanship or inferiority and insufficiency of materials. Cases have unfortunately not been unknown in which large portions of walls have given way under pressures or adverse conditions which they should have been capable of resisting, and instances are too common in which the reaction from unnecessarily thick walls has been carried to a dangerous extreme, or in which deplorably inferior material has been used. To insure the essential degree of stability, it is necessary that an upright wall should be properly constructed upon a sufficient foundation, and that due precautions should be taken against the effect of pressures created by various parts of a building.

Selection of Materials.—The selection made of the different materials in general use, including stone, brick, timber, and iron, and the respective merits of the particular supplies introduced, affect stability. It is supposed that a brick wall properly constructed is a better basis for a stable structure than stone in the form of rubble, but that the most perfect stability is to be obtained from carefully-dressed and accurately united and bonded blocks of stone, mortar being used to no greater extent than is necessary to exclude wind and water. Various kinds of stone, however, differ widely in their durability and their power of resisting the effects of intense heat. In the selection of stone fitted for general construction, desirable qualities are relative freedom from a tendency to absorb moisture and comparative ease in working or dressing into appropriate sizes and shapes.

Thickness of Walls.—A leading consideration in the determination of the thickness of walls is their height. But other conditions affect this subject, such as the extent to which the main wall is strengthened, and the necessity for thickness diminished, by chimney-breasts or other buttress-like projections, and the extent to which the main wall is weakened by spaces devoted to door and window openings or by subjection to unusual pressures. The thickness of walls required in the erection of dwelling-houses and buildings other than dwellings is prescribed by laws enforcible in some of the leading cities of the United States. The provisions of the statutes applicable to the city of New York include the following: For a dwelling-house in which the height of walls is not to exceed 55 feet, the thickness of the foundations if of stone must be not less than 20 inches, and if of brick not less than 16 inches. The thickness of the external and party walls must be not less than 12 inches. For dwelling-houses exceeding 55 feet, but not exceeding 80 feet, stone foundations must be not less than 24 inches in thickness, and brick foundations not less than 20 inches; the exterior wall must be not less than 16 inches thick to the top of the second floor, and 12 inches thick in the remaining height, if it is not more than 40 feet, and party-walls must be not less than 16 inches in thickness. So far as the requirements relating to dwelling-houses more than 80 feet high, and buildings other than dwellings, differ from those mentioned above, they represent an increase in the thickness of foundations and walls.

Materials: Brick.—In large cities and towns of considerable size bricks usually form the principal material of the walls of a large proportion of the buildings erected. They vary considerably in size, color, and quality, some of the differences being caused by variations in the clay used, and others by diversified effects in the process of manufacture. The bricks used in the Eastern States are of a smaller size than those manufactured in the Middle and Western States. The usual dimensions of Baltimore-front, Philadelphia-front, Wilmington-front, and Trenton-front bricks are $8\frac{1}{4} \times 4\frac{1}{8} \times 2\frac{3}{8}$ inches. Maine bricks are $7\frac{1}{2} \times 3\frac{3}{8} \times 2\frac{3}{8}$ inches; Milwaukee bricks are $8\frac{1}{2} \times 4\frac{1}{8} \times 2\frac{3}{8}$ inches. Bricks of a nominal size, however, are subject to variations in dimensions and weight, and in other qualities. Ordinary London bricks are called $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches, but they are frequently only $8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{1}{2}$ inches. Approximately, bricks possess the advantage of uniform size and shape, and their power of resisting fire is much greater than that of some of the stones used. Characteristics of good bricks are regularity of shape; the emission of a clear ringing sound when they are struck; the display, when they are broken, of a compact uniform structure, hard, somewhat glassy, and free from air-bubbles and cracks; and inability to absorb more than about one-fifteenth of their weight of water. It is considered a useful precaution carefully to inspect bricks supplied for important buildings, and to reject such as are defective. Compressed bricks have considerably more strength and weight than ordinary bricks.

Enamelled Bricks, and Terra-cotta.—A desire to diversify brick fronts so as to produce decorative effects, is, with other causes, leading to an increased use of various forms of enamelled brick, or brick of different colors, and terra-cotta moulded in ornamental forms (*pl.* 2, *figs.* 1, 4). In connection with such uses, terra-cotta is defined as a superior variety of brick, each piece of which is specially moulded. Quality depends largely upon the characteristics of the clay used. An advocate of terra-cotta for facing street-fronts says that when properly burned it is impervious to smoke and unaffected by acid fumes of any description, is about half the weight of the lightest building-stones, and is easily moulded into any shape for cornices, window-sills, architraves, or other purposes. Differences in color, including yellow, red, and, when it is glazed, soft browns, greens, reds, or yellows, are attainable. Terra-cotta sometimes forms the substance of drain-pipes, and of porous blocks used in fire-proof buildings in connection with iron girders.

Stone.—The stone employed in construction at various times and places includes a number of varieties in addition to those to which particular reference is made. In many situations common building-stone serves as the principal supply for foundations. Changes in the favorite material of different localities for fronts and entire structures occasionally occur on account of the opening of new quarries or the discovery of unexpected defects. Some of the latter could presumably be avoided by the exercise of greater care in the selection of stones from a given quarry. A useful hint bearing on this subject may be derived from the statement that when Sir Christopher Wren built St. Paul's Cathedral he had the stone he intended to use quarried and exposed to the weather on the sea-beach for three years before any of it was placed in the building. By similar precautions the stones taken from other quarries have been rendered serviceable for centuries, while on account of their omission, or from other causes, the spectacle of rapid decay or disintegration of portions of pretentious fronts is sometimes presented in this and other countries.

Granite.—Among materials for superstructure of important buildings, granite holds a leading rank. In the United States several varieties have been introduced and used in the construction of large public edifices, stores, churches, etc. On account of its hardness, special skill in dressing it is required; but such difficulties have been overcome to a great extent by the employment of skilful workmen at various places where it is quarried and dressed or ornamented before it is sent to its final destination. Prominent varieties include the Quincy granites, which have furnished the material for a large portion of the granite structures in Boston; Maine granites, embracing red or pink, as well as varieties of other colors; New Hampshire, or Concord, granites; a granite obtained from quarries located near Richmond, Virginia, which furnished the material for several of the department buildings in Washington. Quarries have also been opened in Rhode Island, Connecticut, Pennsylvania, Missouri, and other States.

Sandstone.—A number of varieties of sandstone, including brownstone, have been extensively used in some of the American cities as the material for the fronts of high-class dwellings and other buildings. The extensive quarrying of brownstone was commenced, and has been continued during a protracted period, in the vicinity of Portland, Connecticut. Unlike granite, it is usually dressed after it has reached the place where it is to be used. Sandstones of various qualities and colors are obtained in a number of States, including Massachusetts, New Jersey, Pennsylvania, Maryland, Ohio, and Wisconsin. In addition to the brownstone of Connecticut, prominent varieties include bluestones of New York and Pennsylvania and Euclid bluestones and Berea grits of Ohio. Beautiful sandstones of warm and mellow tints have been found in many of the Western States and Territories.

Limestones are classified as compact, magnesian, or oolitic. In England some of these varieties have been extensively used, and in the United States they have frequently furnished the material for the dwellings erected in or near limestone districts. English authorities consider that the most important subdivision of the limestones used in masonry is the oolitic, and they place a very high estimate on one of its varieties, the Portland stone, of which superior specimens were selected for use in St. Paul's Cathedral. It is one of the few stones unaffected by the smoke of London, and this fact has greatly increased its use in that city. In the United States, Indiana furnishes superb oolites which are extensively employed. This stone has a pleasing warm tint and is soft enough to lend itself readily to the most elaborate ornamentation.

Travertine is defined as a limestone of porous texture formed by deposition from mineral springs. It has a warm color, may be quarried in large blocks, and is extensively used at Rome, in both ancient and modern buildings, including the Cathedral of St. Peter's.

Marble.—There is no substantial difference in composition and origin, in a scientific sense, between ordinary limestone and marble. The notable extent to which marble has been used in important structures, as the exterior of the Capitol building at Washington, and other exceptionally extensive and costly edifices in the United States, is presumably due partly to the historic and artistic interest felt in the material, and partly to its inherent beauty, its susceptibility to a high polish, the readiness with which it can be dressed or fashioned into any desired shape or form, and its attractive varieties in color. Quarries have been opened in Vermont, Massachusetts, New York, Pennsylvania, Maryland, Tennessee, and Georgia, and deposits exist in a number of other States. The annual value of the native product at a comparatively recent period was about two million dollars, of which more than one-half was quarried in Vermont; considerable quantities are also imported, chiefly from Italy. A number of the native marbles are used principally for general building purposes, instead of decorative work. But marbles found in East Tennessee have attracted much admiration, and have been introduced to a considerable extent since their use in portions of the interior of the Capitol at Washington. Their colors are peculiarly attractive, as they vary from light pink mottled with white through all shades to deep chocolate red, thus affording a pleasing diversity, and their texture combines closeness and compactness with nearly absolute freedom from flaws.

Concrete may be defined as a sort of liquid masonry which, poured from a height into a mould prepared for its reception, hardens into a mass of solid stone. The materials generally used in its composition are gravel and broken stone mixed thoroughly with lime while water is thrown upon the mass, which while still warm is poured from elevated stages into the trenches dug to receive it. When work is done very hastily, as the lime may not be thoroughly slaked and the process may continue with injurious effects, it is recommended that the concrete, immediately after mixing, be gently tipped from wheelbarrows into the trench prepared, and rammed down in layers about a foot in depth. When broken stone or masons' chips are used for the compound, sharp sand is added. As a general rule, the pieces of stone should never be larger than a hen's egg. Thorough and careful mixing of the components greatly increases the value. Hydraulic lime and the addition of volcanic sand improve its quality, and an excellent composition is formed by the mixture of Portland cement with sand and gravel.

Timber and Lumber.—Wood in various forms and of sundry kinds continues to be used extensively in the interior arrangements of nearly all American buildings, and to furnish the exterior material of a large number of the dwellings located in rural districts, villages, and towns. The articles quoted in price-lists of builders' materials include different qualities of pine, pine boards, pine plank, spruce boards, spruce plank, spruce wall-strips, spruce timber, hemlock boards, hemlock joist, ash, oak, maple, chestnut, cypress, black walnut, cherry, whitewood, yellow dressed pine flooring, yellow pine girders, locust posts, and chestnut posts. Estimates of the cost of designs for cottages frequently embrace a liberal allowance for timber bills and for other wooden materials, including those used in flooring, verandas, balconies, windows, doors, and stairs. A large proportion of the dwellings erected by the early settlers of nearly all localities in the United States was composed chiefly of wood, and this custom continues to prevail to a considerable extent, the ordinary course of progression being from log cabins, frame or weatherboarded houses, to stone or brick dwellings.

Strength and Durability of Timber.—It is said that there are certain indications characteristic of strong and durable timber, which include the following: (1) In the same species of timber that log will, in general, be the strongest and the most durable which has grown the slowest, as shown by the narrowness of the annual rings; (2) The cellular tissue should be hard and compact; (3) If the wood is colored, darkness of color is generally a sign of strength and durability; (4) The freshly-cut surface of the wood should be firm and shining instead of dull and chalky; (5) In wood of a given species the heaviest specimens are generally the strongest and most durable; (6) Among resinous woods those which have least resin, and among non-resinous woods those which have least sap or gum, in their pores are generally the best. Superior qualities of timber are free from such blemishes as clefts or cracks radiating from the centre, cracks which partially separate one annual layer from another, wounds in a layer of the wood which have been covered or concealed by the growth of subsequent layers over them, and hollows or spongy pieces in the centre and elsewhere, indicating the commencement of decay.

Grades of Lumber.—The nature of recognized defects in hard-wood lumber is shown by provisions in the Boston law for the survey of black walnut and cherry, oak, poplar, and butternut, which require that the woods be divided into three grades—namely, number one, number two, and culls. Number one includes all boards, plank, or joist that are free from rot and shakes and nearly free from knots, sap, and bad taper; the knots must be small and so far sound that they would not cause waste for the best kind of work. A board or plank with a split parallel with the edge of the piece is classed as number one. Number two includes all other descriptions, except when one-third is worthless. When a board, plank, or joist contains sap knots, splits, or any other imperfections combined, making less than one-third of a piece unfit for good work and fit only for ordinary purposes, it is number two. When one-third is worthless, it is a cull, or refuse. Refuse or cull hard wood includes all boards, plank, or joist that are manufactured badly by being sawed in diamond shape smaller in one part than in another, split at both ends or with splits not parallel, large and bad knots, worm-holes, sap, rot, shakes, or any imperfections which would cause a piece of lumber to be one-third worthless or waste. All hard woods are measured from 6 inches up, and all lumber sawed thin is inspected as if it were of proper thickness, but is classed as thin and sold at the price of thin lumber.

Iron.—The use of iron in the construction of large and important buildings, and various classes of shops, mills, stores, and factories, is increasing. The purposes to which it is applied include the support of walls, floors, and roofs. In addition to a growing demand for standard qualities and shapes, iron, either corrugated or galvanized, is being used to an increasing extent for roofing, and in some cases for exterior surfacing. The available appliances include cast-iron columns; hollow cylindrical or rectangular cast-iron pillars; cylindrical cast-iron columns; wrought-iron posts and columns, I-beams, channels, T-bars, angle-irons, and deck-beams used as posts; rolled beams and channels used as struts; angle and T-bars used as struts; wrought-iron rivetless columns; riveted plate-iron girders; cast-iron arch girders with wrought-iron tension rods; and stirrup-irons. Ample provision is made for variations in the weight and strength of each of the standard articles, and ingenious devices for combining component parts have been perfected. Great progress has been made in the United States, during a comparatively recent period, in many things pertaining to the use of iron in construction. Galvanized iron is sheet iron covered on both sides with a thin film of zinc, which is applied mainly because zinc resists corrosion from ordinary atmospheric influences much better than iron. Corrugated iron, which may or may not be galvanized, is sheet iron in corrugated forms. Advocates of the use of corrugated iron—which, as a covering for buildings, is now made in improved forms—allege that it is fire-, water-, and wind-proof to a high degree; that the corrugations lend the iron considerable additional stiffness, on which account, the strength acting as a support, framework may be comparatively light; and that corrugated sheeting is cheap and durable if properly painted.

Combination of Materials.—Various combinations of materials are extensively used in building operations, to some of which more particular reference will be made hereafter. General suggestions bearing on this subject embrace a statement that, while two kinds of materials sometimes have the effect of improving or strengthening a wall, in other cases they produce the opposite result. It is said that a stone-rubble wall is improved by bonding courses of brickwork at short intervals, and that a brick wall is improved by thorough courses at intervals of good stone properly adjusted, but that elements of weakness rather than additional strength are introduced when a stone-rubble wall is faced with brickwork or when a brick wall is faced with wrought stone.

Scaffoldings.—The bricklayer's scaffold is usually carried up with the wall and made to rest upon it. The scaffold consists of standards, ledgers or runners, putlogs—sometimes called "putlocks"—sheeting or scaffold boards, and braces. The standards are poles, which are placed from 10 to 12 feet apart in a row about 4½ feet from the wall and parallel with it. These standards, which are firmly fixed in the ground or planted in tubs of earth or mortar, are from 20 to 50 feet long, and can be extended by splicing. The ledgers or runners, which are poles secured to the standards by ropes, lie horizontally, parallel with the wall at the level of the highest course of bricks laid. The putlogs or putlocks are cross-pieces, generally of sawn birch, about 6 feet long and placed from 4 to 6 feet apart. They are fixed at one end in the wall, on the middle of a stretcher occupying the place of a header, which is to be afterward inserted. The other end of the putlogs, which make the platform upon which the bricklayer stands, rests on the ledger.

The sheeting or scaffold boards form the gangway, and the braces are poles lashed diagonally across and outside the standards for further security when the scaffolding is run to a great height. The mortar is usually placed on boards about 3 feet square along the putlogs, with bricks, to suit the convenience of the bricklayer. As the work is continued another ledger is rigged up above at a distance of about 3½ feet, that the bricklayer may insure good work by never laying his bricks at too great a height.

The supply of brick and mortar is furnished constantly from below, with due care that the ledgers are never overloaded, so as to rest too heavily upon the newly-laid courses. Rubble walls can be erected from the scaffoldings just described, but in better styles of masonry and in large buildings the scaffolds are built double, a second row of standards being so fixed as to carry the inner ends of the putlogs and avoid any injury to the wall, while securing a firm platform for the workmen.

The suspended scaffold is a convenient arrangement for painting or pointing a house-front without obstructing the sidewalk. A platform of planks makes a sufficient space for the workmen, who can lower or raise it at will by ropes and pulleys made fast to beams projecting from the upper windows or secured to the roof-timbers. Various new devices are introduced in American cities from time to time which presumably represent improvements on old methods of scaffolding and of furnishing brick and mortar to bricklayers.

Precautions against Fire.—The aggregation of population in cities, the immense increase in manufactures, the introduction of gas and steam, the discovery and extended use of petroleum, and the vast extent and altitude of building structures, are all tending so to multiply the sources of conflagration that precautions against fire are becoming of vital importance to the community. The employment of incombustible materials in architecture would seem to afford one of the best of preventive methods. The modes of building in many countries of continental Europe secure great safety in this respect. This immunity is obtained by the use of massive walls with incombustible filling between joists and rafters, roofs of terra-cotta tiling, brick or stone partition walls, and floors and stairways of tile or marble. Timber impregnated with a solution of copperas is regarded as a fire-resistant, and shingles, window-frames, and cornices could be well protected after being placed in position by coating with solutions of such fireproof salts as alum, copperas, and borax, and also with paints containing the same materials. This precaution would be most serviceable in the country, where isolated dwellings are frequently of wood and are much endangered by fire.

Concrete as a building material has been well tested as a fireproof composition, and ordinary plaster, if of sufficient thickness, has shown great resisting quality. Brick walls built so as to allow proper settling and bedded in mortar containing Portland cement furnish a most valuable obstacle to flame. Mortar of good quality has in itself, when aided by brick, a supporting quality which gives a certain elasticity to the wall and breaks the heat-conduction of the brick, its granular formation yielding to torsion and strain without breaking. Hollow bricks have a greater relative strength, lightness, and elasticity, but the air in the interior spaces may expand dangerously in case of fire, if means of escape are not provided. In a thick wall the interior bricks should be entirely encased in mortar, adding much to the supporting and resisting power. Stone walls of irregular and rather small pieces have less ability to resist fire than brick walls; but when they are of ample thickness and are well laid in sufficient mortar, they may be estimated at the strength of brick walls of half the same thickness. Large stones, although necessarily built with less mortar, have by their great weight a resistance to vibration under fire.

Lofty buildings have an increased danger from fire, on account not only of the tendency of flame to ascend, but also of the disintegration arising from the tremor or vibration in high walls, particularly when subjected to the incidental movements of machinery, etc. When brick walls are not of excessive height, they regain elasticity after cooling, and are often used in re-building after conflagration. In order to erect a fire-proof building it has been proposed to employ concrete for floors, washboards, ceilings, cornices, sides, lintels, casings, and mouldings of doors and windows. The partitions would be brick, and the stairs either of terra-cotta, concrete, or stone slabs resting upon brick arches. An incombustible filling would be placed between wooden joists, with a concrete ceiling supported by a netting of wire. The roof with its supports would be constructed like the floors, and covered on the outside with copper, concrete, or thick galvanized sheet iron. Brick piers for supporters, upon heavy brick arches, would complete the edifice.

II. CONSTRUCTION IN STONE.

Structures in stone appear either in massive form as masonry or more specifically as stone along with framework and the shell-like form known as face-work. The choice of the building material, which may be either natural or artificial stone, will depend on the nature of the service for which it is designed. Natural stone which can be worked into regular shapes—as, for example, granite, sandstone, and marble—is designated as "cut stone," while that used in irregular shapes is called "broken."

Natural Stone Walls.—Stone of all kinds, being rough in the natural shape, must for every portion of a building except foundations be shaped into forms suitable for its position. In so doing there should be considerations as to economy of mortar and cement and provision for ornamental designs. Stronger walls may be built of stone than of brick (though those composed of the latter will stand far more heat in a conflagration), and such stone is either rough or hammered, with edges dressed true from ¼ inch to 1½ inches around the four joints of the front, or plain and very perfectly fitting pieces are chiselled smooth or highly polished, as in granite, both forms being often intermingled in the fronts of buildings. Stone, usually granite or sandstone, either rough or smooth and polished, is now extensively employed for the largest and best buildings in the chief cities of the United States. The rough is not confined to any particular portion of the front or sides, but is used much for arched work, and chiefly in the basement or first story.

Rubble Stone Walls.—Rubble-work for walls is very common in the United States and Europe; in the former country some small towns are built almost entirely of it, where the stone can be conveniently obtained.

A typical instance is the older portion of the suburb of Philadelphia known as Germantown. Irregular stones, large and small, such as are used for foundations and cellars, are built in walls of from two to four stories' height, with sufficient cheap mortar similar to that made with gravel and lime, care being taken to fill all interstices with small fragments of stone. The outside can be finished in stucco or by pointing the joints with better mortar. To prevent dampness, the walls inside are often stripped with wood before plastering. Many very costly rural dwellings, barns, and even public halls and school-houses, in the United States are constructed of irregular pieces of the best kinds of stone, in the same manner as above stated, the best mortar being used. The inside half or two-thirds of the walls of such buildings are frequently composed of ordinary rubble-stone and the more common descriptions of mortar.

Artificial Stone Walls.—Air-dried bricks (for adobe structures) are formed chiefly of clay; if hardened by fire, they are called burned bricks. Buildings of materials known variously as concrete, béton, Pisé, etc., must be included under the head of constructions in stone, as the mass, though at first soft, so that it can be moulded to take any desired shape, soon hardens and becomes in all respects similar to stone. Concrete and béton walls are composed of small pieces of stone mixed with gravel, sand, and cement; of the last there are many kinds, of which the celebrated "Portland" is a prominent type. The plastic material is rammed tightly into strong wooden moulds, which are allowed to remain until the work has set, and are then moved upward. This description of walls has been adopted to a considerable extent in England and France for medium and small houses, but has as yet been but little used in the United States.

Concrete Walls.—In concrete walls, whose structure is shown in Figure 10 (*pl.* 1), the applied material is hydraulic mortar mixed with fragments of stone, rubble, etc.; sometimes a mixture of lime and sand only is used. The picture is taken from Lacroix's *Études sur l'Exposition* (Paris, 1867), and exhibits the manner of constructing workingmen's houses of such concrete walls. As will be noticed, pillar-shaped moulds are first erected at the corners and central parts, between which, as the work progresses, the horizontal moulds are gradually moved upward in the same manner as above stated.

Pisé Walls.—In some parts of Europe the cheap Pisé work is much used for small houses of two and three stories. Fat loams are mixed with water and gravel (sometimes sand or chopped straw), without cement, and this medium-wet compound is forced into moulds similar to those used for concrete walls. Openings for doors and windows are finished with wooden frames held by iron clamps built into the walls, and can be ornamented with mouldings. Stone and brick decorations may be inserted in the walls, wood not being suitable for such a purpose. The outside, when entirely dry, is usually stuccoed; the inside is roughly plastered, but can receive finer finish if desired.

Binding Material: Mortar.—The material usually employed in binding structures of masonry is aërial mortar, a mixture of lime and sand. In certain cases, to prevent dampness or to secure greater solidity, a binding material known as cement, with or without admixture of sand, is largely used, and is especially adapted to the construction of bridge piers and abutments. There are several kinds of mortar. The cheaper kind, such as above named, is formed with gravel and lime; the common is composed of sand and lime, the better qualities of the last named containing a certain quantity of cement.

Lime is obtained by heating the natural carbonate of lime (limestone) to a high heat in kilns, thus driving off the water and carbonic-acid gas, whereby the weight is diminished about fifty per cent. When about to be used, it is formed into a hydrate by immersion in a proper quantity of water (not an excess), whereby a large volume of heat is given out and the mass becomes soft and pulverulent. When further treated with water to form a paste, carbonic acid is absorbed by it from the atmosphere, and the mortar begins to crystallize, and further hardens after its application to brick or stone; and this phenomenon continues for many years, which explains the fact that the older the mortar, if good, the more it approaches the hardness of stone.

Lime can also be made from chalk and marble, but the former, containing much more water than limestone, heats irregularly in the kiln and is often imperfectly burned, resulting in not slaking fully when needed for use. Some affirm that this description of lime absorbs more carbonic-acid gas than any other kind, but this has not been fully proved. Much care is needed in the selection of crude material if good lime be desired, since poor limestones contain silica, magnesia, and metallic oxides. As these may vitrify during calcination, the lime formed will not slake freely. Poor limes may, however, be much improved by grinding them just before slaking, and in such case they may even exceed in durability richer unground limes, especially where water is likely to be near or often to attack the foundations of walls built therewith, or foundations supporting walls built with mortar formed from such ground lime. Magnesian limestone, when used for producing lime, yields a product that has the disagreeable quality of causing an unsightly efflorescence on walls, especially of brick, in the erection of which it may be employed.

Lime used for mortar should be slaked only when about to be mixed with sand and water, and the proportions for good mortar should be one of lime and three of sand; with use of the best sharp sand and the best lime, four parts of sand may be employed, but this is about the limit. A small quantity of sulphate of lime in the form of plaster of Paris added to mortar will cause it to set much more rapidly and to yield greater strength than ordinary mortar, while allowing the use of a much larger proportion of sand. This kind, where more of the sulphate is added, is even used as a substitute for hydraulic cements in forming concrete, etc.

Sharp river-sand is the kind usually mixed with lime to form mortar, the best of the latter having an admixture of ground quartz or flint, which greatly improves the adhesive quality. Some maintain that very sharp sand or crushed quartz with an inferior lime forms a mortar much superior to that from soft sand, even though the best lime be used with the latter. Burned clay will form a fair lime, but such is not to be recommended for the better class of work, especially that subjected to dampness. It may be improved by mixture with hydraulic lime, ground ashes, and sharp sand. Slag from iron furnaces, when properly ground, may be used instead of sand, and with good lime produces an excellent mortar. Ground coal-ashes, if used at all, should be used sparingly.

Hydraulic Mortar or cement is that formed entirely of certain kinds of argillaceous limestones finely pulverized, which when mixed with water alone form the strongest kind of bond; and the better descriptions will, as above stated, harden under water. There are various rocks containing nearly seventy-five per cent. of carbonate of lime which, when burned and afterward ground, can be used with water as hydraulic mortars without mixture of sand. These form what may be called the medium cements, not hardening under water, but obtaining quickly great firmness and durability in the atmosphere. Portland cement, already mentioned, and others resembling it, such as imitations made largely in the United States, form the best hydraulic mortars. Cements are mixed with sand, in the proportion of from one to three of sand to one of cement, along with just enough water; but mixture should be made of them only as they are required for use. The addition of sand in small proportion appears to have a favorable influence on the binding quality and ultimate hardness of the cements. In larger proportions, it has a weakening effect. The better descriptions are frequently used in a fluid condition, called "grout," to flow in among and bind the parts of certain kinds of masonry; in such case but little sand should be used.

Pozzuolana, a volcanic product found near Naples, Italy, when ground and mixed with equal portions of lime and sand, or five of pozzuolana to two of lime, forms one of the best of bonding materials, hardening very rapidly even under water.

Bonding of Masonry.—In masonry required for vertical enclosures the bonding, or union of individual pieces composing the structure, is indispensable, as it not only insures stability to the walls, but also contributes materially toward effecting a distribution of pressure throughout the building. The only exception is found in the case of plastic materials which cannot be bonded together in the above sense. In bonding, particular attention must be paid to the arrangement of the joints, as a distinction must be made between those lying between the superposed courses of the work (coursing joints) and those between the individual stones of a course (heading joints). The principal rule to be observed for a perfect bond is that the heading joints of the superposed courses shall never be placed either wholly or in part over one another.

Bond and Masonry in Brick.—Owing to the relatively small size of bricks, the application of mortar is an important element in securing solidity in a wall. The thickness of the layer of mortar in the joint is generally about $\frac{4}{10}$ of an inch, and this comparatively heavy layer gives the wall a characteristic appearance. To obtain a regular bond, the brick, which has the shape of a parallelopiped, must have dimensions determined by fixed rules, the length being at least twice the breadth. This proportion is observed uniformly throughout the German empire, where the dimensions for length are $9\frac{3}{4}$ inches and for width $4\frac{3}{4}$ inches, calculating the width of joint at $\frac{4}{10}$ of an inch. Though a similar proportion between the breadth and the thickness might be desirable, it would weaken the brick, so that it would be very liable to fracture.[1] The bond is always to be so arranged that, with the exception of corners, whole bricks only are used for the mass of the wall; and for this reason the thickness of brick walls is specified according to the length of the bricks. The bond may, however, admit of great variation. There should be distinguished the "block bond" and "cross bond," and more rarely the "Gothic" or Polish bond.

Block and Cross Bond.—In the block bond (*pl.* 1, *fig.* 1), the bricks in one and the same row lie either with the long side (stretcher) or the narrow side (header) forward. The difference in the two bonds is that in the block bond there is a mere alternation of the stretching and heading courses, so that the heading joints of all the headers, as well as those of the stretchers, stand over one another, while in the cross bond (*fig.* 2) this applies to the headers only, and not to the stretchers, as the latter have an alternation of the heading joints among themselves. Consequently, in the block bond, as shown in Figure 1, the toothing is regular on the sides, while the racking is irregular; but in the cross bond (*fig.* 2) this arrangement is reversed.

The disposition of bricks laid on the inside of a wall will depend upon its thickness (in Figures 1 and 2 a wall of the thickness of two bricks is supposed). In walls whose thickness is divisible only by half-bricks, as one and one-half, two and one-half, etc., if a row of stretchers be at one side, there is a row of headers at the other side, and the reverse in the next course, etc. In other respects the thickness of the wall will not influence the exterior appearance of the bond. To lead in the bond at the corners, as shown by the Figure, the wall is started either with a three-quarter brick in each stretching course, or in the heading courses with a brick of one-half width, inserted immediately behind the first header.

Gothic Bond.—In the Gothic or Polish bond—which according to the above rule cannot be called perfect—stretchers and headers are alternated in the same course, as shown for cut stone in Figure 8.

Hollow Walls.—Recently, hollow bricks have been extensively used; thereby the weight of the wall is diminished, though the bond is not altered. The weight is also lessened through making the wall itself hollow by spaces left between bricks, as seen in Figures 3 and 4; here the Gothic bond may be used to advantage. In Figure 3 common bricks are supposed,

[1] This proportion would make the brick only $2\frac{1}{5}$ inches thick, while the thickness ordinarily adopted is $2\frac{3}{5}$ inches.—ED.

and it is only necessary to lay a quarter-brick before each header that there may be a corresponding hollow in the wall, which will then be one-and-a-quarter bricks in thickness. In Figure 4 (*pl.* 1) the bricks are supposed to be square in cross-section, with a side of about 4 inches; the cavity, with bricks 10 inches in length, would then be only 2 inches and the wall one brick thick. Hollow bricks and fire-clay tiles of various forms used for interior construction, as for partitions, spanning spaces between girders of iron, etc., will be considered in the section specially devoted to the subject.

Bond and Masonry of Regularly-shaped Stone: Ashlars.—In bonding ashlars, which are larger and heavier than bricks, mortar becomes of minor importance; in fact, it may be dispensed with. Where the joints are closely fitted, it is usual simply to pour in milk of lime or thin cement-mortar. Considering the greater weight of the stones, it is unnecessary to adhere strictly to the rules above given for bonding. Figure 5 represents a wall of ashlars of alternately high and low courses; Figure 6, one in which the ashlars are used only as a facing for a wall built of other material; and in Figures 7 and 8 are shown walls in which such stone facing is desired on one side only—in the former, alternate high and low courses, and in the latter, courses of equal height.

As a rule, the ashlars are quadrate in section and have a length, in the case of very dense stone (such as granite), equal to five times, and in solid stone (as marble) to four times, the height; in stone of medium strength (like sandstone) to three times, and in less substantial stone not more than double, the height. When the ashlars form a facing only, then, as with the Gothic bond, there must be used with cut stone as many headers (binding stones) as possible. The treatment of ashlar work on the exterior varies greatly, depending on the character of the building or of the parts to which it is applied. If the effect of strength is to be given, "bossage" or rustic work (*fig.* 9) is used, as in the parterre of the Dresden Museum. A similar result is obtained by bevelling the outer surfaces; sometimes also ornamental ashlars are employed. A fine example of ashlar work is the entrance to Austin Hall, Harvard University (*pl.* 2, *fig.* 2).

Masonry of Approximately Regular Stone.—Examples of approximately regular stone masonry are to be found in remains of constructions by the Pelasgian races, the "Cyclopean" or polygonal walls (*pl.* 1, *fig.* 12). The huge stones of this masonry were carefully joined without mortar. Respecting the joining of walls made of irregular stones, it will only be necessary to say that attention must chiefly be paid to evenness of courses and horizontal bedding of stones, no systematic alternation of joints being possible in this case.

Stone Framework differs from masonry in not dealing with the disposition of masses, but rather with the erection of framework made of single or beam-like parts (posts or pillars, lintels). The finest example of this construction is seen in the Greek temple (*fig.* 11), in which the covering by stone beams (architraves) of the spaces left between supports or columns is especially remarkable, in so far as in this form of covering the side-thrust present in vaulted coverings is entirely absent. As the porticos of their temples show, the Greeks used this system also for the covering in of spaces, hollow pieces (*lacunaria*) being set between the stones and beams placed at fixed intervals. The employing of stone framework, and especially the covering of spaces with stone beams, will always be limited in modern buildings, since, on account of their inferior tensile strength, stone beams cannot, like wooden or iron beams, be permitted to stand free over large spaces. Where arches or walls are set between the bays of stone frames, the case is quite different. These arches or walls are then the real, the pillars being only apparent, supports.

Vaulted Coverings (arches) are used over openings in walls as well as over entire rooms (vaults proper). Every vaulting may be regarded as a pendent wall in which the sustaining of the individual parts (arch-stones or voussoirs) is effected in such a manner that by properly forming and placing these stones (generally wedge-shaped) in position the pressure of those above, or any additional weight, is transferred from each stone to its neighbor obliquely downward upon the side walls (abutments); these must be of sufficient strength to carry the weight of the entire vaulting. The advantage of vaulting is that, unlike the case of the free-lying stone beams, it is not a question of resistance to bending, but of resistance to pressure, and consequently, regarding the width of span, the builder is not so strictly limited. It was formerly supposed that the ancient Greeks were not familiar with the arch, but the fact that there have been found remains of vaultings constructed by that people justifies the conclusion that they rather disdained the use of this architectural expedient. On the west coast of Northern Greece there is an old arch (*pl.* 1, *fig.* 12) which, built without mortar, has a span of 14¾ feet.

Different names are applied to arches, partly derived from the form of the arch-line—that is to say, the inner boundary-line of the arch-stones (voussoirs)—and partly from the general form and arrangement. The arch-line may be a semicircle (as in Figure 12), a segment arch, an elliptical arch, a pointed or Gothic arch, etc., or even a straight line (flat or straight arch). According to their general form, these structures may be classified as cylindrical, groined, coved, spherical, and fan vaults.

Cylindrical or Barrel Vaults may be regarded as part of a hollow cylinder with an arch-line in any form. All arches in a wall (for example, *fig.* 12) should be regarded as short, cylindrical vaults. As a ceiling, the cylindrical vault is generally used in long spaces, such as corridors, or in long bays divided up by "transverse arches." A peculiarity of the cylindrical vault is that it transfers its thrust upon only two sides, while it is merely in contact with the other two walls. If there are openings in these resisting walls, whose crown is on a higher level than the springing of the vault (that is, above the starting-point of the vault), lunettes are built in, which spread—sometimes in an oblique direction—toward a corresponding cut in the main vault. These lunettes may find application when, like that over the stairs in Figure 17, a vault spans on arcades.

The material for the cylindrical vault, as for most vaults used for covering, is generally brick. The curve of the arch is obtained either by cutting the bricks, or by making wedge-like heading joints, or by using specially-formed wedge-shaped bricks. The bond will depend on the thickness of the vaulting, which, when carefully carried out, will in most instances require only a half-brick for spans of about 12 feet and less. In this case the bond is a stretcher, but its direction will admit of variation, as the courses (coursing joints) may run either parallel with or perpendicularly or diagonally to the axis of the vault.

The Groined Vault is to be regarded as resulting from the interpenetration of two cylindrical vaults, with their springings and crowns on the same level. If the lines of both vaults are to have the same form, the ground-plan of the vault must of necessity be a square. Figure 13 (*pl.* 1) exhibits the most simple form of a groined vault of this order, over a quadratic ground-plan; the lines here are those of pointed arches, which, however, are closely akin to the semicircle of the arch-line in the transverse arch. The curved lines (elliptical in semicircular arches) on the under side of the groined vaults, caused by the intersection, are called "groins." As a rule, two arches crossing each other (transverse arches) are first set in the direction of the groins, and afterward, between them, the portions of the cylindrical vaults (sectroids); the under side of the transverse arches may either be flush with the surfaces of the vaults (that is, without projection), or, as in the case of Figure 13, made visible in the form of a bead or other profile, and provided at the crossing-point with a conspicuous keystone boss). If the groined vault be used, not over square plans, but over those which are oblong, either the arch-lines of the intersecting barrel vaults must vary in form, or, at least, if the form be the same, the smaller two portions of the vaults must have a rise toward the vertex. This may be done either in a straight direction or in a slight curve, and is very frequently extended to all portions of the groined vault.

Groined vaults may be built over apartments which have many sides, whether they are regular or irregular. In this case it is only the number of the cylindrical portions intersecting one another that is increased, and, as regards the common vertex or intersecting point of the groins, the centre of gravity of the ground-plan is calculated therefor; where the ground-plan is a regular polygon, this will be the centre point. If large apartments are to be arched, groups of groined vaults are frequently adopted, the apartments being divided into sections as nearly square as possible by means of pillars and transverse arches, as shown in Figure 14.

Lierne Vault.—The vaulting shown in Figure 14 is not a pure groined vault, but a "lierne," where the surfaces are divided not only by the diagonal ribs, but also by intermediate ribs, into numerous sections; so that the ground-plan is in the form of a star. This species of vaulting, which is very rich in effect, is often employed in the Gothic style; the one represented, which is an example of very bold vaulting, is taken from the Marienburg Castle, a Gothic structure in West Prussia. The Figure shows the vaulting of the Grand Hall (*Remters*), which has a slender supporting pillar in the centre.

In regard to the distribution of pressure in groined vaults, it may be remarked that the enclosing walls, even where there is a rise toward the vertex, receive very little of it, but more is thrown on the corners; on this account the latter are often strengthened by pillars, the walls being of moderate thickness. In reference to the thickness of groined vaults, it is stated that for spans of about 16½ feet the diagonal ribs need be only one brick wide and thick, and the sectroids only one-half brick.

The Coved Vault may likewise be considered as arising from the interpenetration of two or more cylindrical or barrel vaults, except that here the sections of the cylinder have another position. They present, not the span-opening, but the abutment sides, to the enclosing wall; and thus arise penetrations which appear as coves on the inner surface of the vault. These vaults, as they begin only above the vertex of the opening contained in the enclosing walls, and thus require great height, are seldom employed.

Spherical Vaults (domes) are of various kinds, but spheres or spherical surfaces are the bases of all; so that the courses are built in horizontal rings, and consequently the vaults can be left open. It may be said that the true dome is formed when a portion of a ring (with any desired arch-line) lying in a vertical plane is rotated about a vertical axis passing through its vertex; which, of course, presupposes a circular ground-plan. In these forms of the pure dome the surmounted elliptical arch is usually employed, under which circumstances there is almost without exception an opening in the vertex, roofed and with arched side windows, technically known as a "lantern."

Hanging Domes.—If hemispherical vaults are thrown over four-sided plans, so that the corners fall into the ground circle of the vault, there will be semicircular penetrations on the four walls, and such vaults (much used in monumental architecture) are called "hanging domes." The vault shown in Figure 15 (*pl.* 1), taken from the Church of St. Mark at Venice, is an example. All the surface is of mosaic, richly decorated, on a gold ground. The illustration shows how in these hanging domes a cornice or horizontal band may be set over the vertex of the wall arches, so that the surface of the vault can be divided into four equal spherical triangles, and a pendent spherical segment, the "calotte." A similar division is possible if instead of a hemisphere a calotte is the basis; in which case the wall penetrations become segment arches and the whole vault requires less height. These vaults when used over oblong ground-plans (not, however, divisible in the manner given) are known as surbased spherical vaults. They are frequently used in private buildings; and it may be remarked that here also up to spans of 16½ feet an arch thickness of a half-brick suffices. The other forms of domes—for instance, the oblate—may be passed over, as they are seldom used.

Fan or Funnel Vaults may be understood by imagining curved lines or sections of circles to be so revolved about the vertical borders of a room or around any of the pillars that they will lie tangentially at their lower ends on the axis. The different parts of the vault thus formed arrange themselves in gently-curved vertex lines; and if the basis-length of the curved line is not equal to at least half the diagonal of the space, or part of the same, they leave above an open space which may be closed in by a small straight vault. The funnel form is seen most plainly at the pillars and when viewed from above; the lower circles are well adapted to ornamentation known as "fan-tracery." Figure 16 (*pl.* 1) shows the top view, and the method of bonding a section of this peculiar vault, which is much employed in the English Gothic style. The example given is from the Cathedral of Peterborough, a building in the "Perpendicular" style.

Arches: Pointed Arches.—English authorities discuss arches from a historical standpoint, treating the earliest as circular. These were succeeded by different forms of pointed arches, classified as lancet, equilateral, depressed, and four-centred, or Tudor. The development of pointed arches commenced during the Middle Ages, and greatly increased the number, beauty, and strength of arches used for decorating churches and temples, and for other purposes.

Arches in Brickwork are classified as plain, rough-cut, or gauged. The plain or common arches are built of uncut bricks and are of the ordinary slope; and, as the bricks nearly touch at the lower points, while a considerable space intervenes between their upper portions, it is necessary that mortar should be freely used to fill the interstices. It is deemed important that this mortar or cement should be of a better quality than that used in ordinary walling, and that the centre on which such an arch is built should not be removed until the work has thoroughly hardened. In large arches moderately slow-setting mortar is considered preferable, so that when the centres are struck opportunities may be left for the voussoirs slightly to accommodate themselves to the pressure. In extensive works involving the adoption of deep arch-rings it has been found advantageous to build the arch in half-brick rings, with a few bonding or lacing courses built in at intervals.

Rough-cut or Axed Arches are constructed of bricks roughly cut to a wedge-shaped form, which permits the use of a smaller proportion of mortar or cement than is required when the structure consists of uncut bricks. The rough-cut bricks are frequently used in small arches set in common mortar when strength is required, and over openings, such as doors and windows.

Gauged Arches are used for superior face-work. They are built of bricks carefully rubbed and gauged to accurately-shaped voussoirs. The joints are made very thin, and the bricks are frequently set in fine lime putty. The English method of manufacturing it is to have pure lime slaked in a quantity of water and strained off while hot, the water being allowed to evaporate till the consistency of cream is attained. The lime is then mixed with silver sand or white marble-dust and worked into the groove with a flat jointer, so as to form a raised line, the sides of which are promptly drawn or cut parallel by drawing the pointing knife along a straight edge, so that the knife trims both edges and scrapes off the superfluous putty, leaving a raised white line standing out on the centre of the joint.

Discharging Arches are built either over or under openings. When constructed over a wood lintel, they should always run clear of both its ends. They may be quadrants of a circle, or even flatter; and if it is considered desirable that they should be turned in, two or more half-bricks should be used over doors and windows and other wide openings, while over the ends of beams it is not necessary that they should be more than one half-brick. Discharging arches under openings are used to equalize the weight over the substructure or foundation. Arches of two half-bricks are deemed sufficient for ordinary purposes, but in large and heavy structures arches of three half-bricks or a greater number may be necessary. Abutments should be provided, whether the arches are erect or inverted.

Stone Stairs.—The principal object in erecting a stairway must necessarily be the securing of a safe and easy communication between floors at different levels, and, that those who ascend it may feel conscious of safety, the strength of the stair should be directly apparent as well as substantial. To render the communication perfectly secure, it should also be guarded by a railing of appropriate height and strength.

Ratio of Gradient.—In all stairs the correct ratio of the gradient—that is, the proper relative proportion between the height of the step (riser) and the breadth (tread)—must become a principal consideration where ease of ascent is of importance. It is claimed that the first attempt to fix this relation upon correct principles was made by Blondel in his *Cours d'Architecture.* His formula, however, was applicable only to large buildings, and not suitable to ordinary dwellings. The absolute measures of the riser and tread must necessarily depend upon the aim and design of the stairway, the riser varying from 5½ to 7½ inches and the tread from 9 to 13 inches; so that the larger tread accompanies the smaller riser, and *vice versa.* The ratio of the gradient may be formed from the rule that two risers and one tread taken together should measure 24 inches. In this measurement it should be remarked that the tread is to be measured horizontally from face to face of risers.

Classes of Stairs.—According to the different positions and uses intended in the edifice, stairways must be distinguished into classes, such as principal and back stairs and outside flights (*perrons*). In material they may be constructed of cut stone, such as sandstone, marble, granite, etc., or of brick in different forms and modes of construction.

The Forms of Stairways are various, beginning with the simplest or straight line, but diversified, according to the necessary adaptation to space and convenience, into triangular, circular, or elliptical, with winding steps, or of mixed forms with straight sides and circular ends. Straight-line stairs, in which every step of the tread is the same throughout the entire length, may consist of several runs or flights. To the latter belong the so-called "double stairs," in which the two flights rise symmetrically to one head, or landing-place.

Stairs of Cut Stone are constructed either as saddled or geometrical stairs. In the former the steps are built for about 5½ inches on either side into the stair walls or arches, which should be at least one brick in thickness; in the latter the steps are walled in for about 12 inches only, lying free at the other end. Furthermore, a mutual foundation of about one inch is given to the steps throughout their whole length, with the intention of obtaining a more even distribution of pressure. Figures 17 to 20 (*pl.* 1) exhibit different forms of principal stairs saddled, while Figure 21 shows the perron, which is richly constructed in cut stone, likewise saddled.

Straight-line Stairway.—The stair seen in Figure 17 is an example of the simple straight-line stair on a grand scale; it is in the Library at Munich, built by Gärtner. Halfway in its length will be seen a so-called *podest*, or landing-place.

Broken-line Stairway.—Figure 18, from a private house in Berlin, shows an elegantly-constructed broken-line stairway with three arms; light is obtained from a skylight. A triple-flight stair of this kind has two landing-places, which will be square if the flights are built of the same width.

Double-headed Stairway.—Figure 19 gives an example of a double stairway with three flights, the upper two of which have the same direction, while the lower one—not entirely visible in the Figure—is common to both. As the part at the uppermost step of a stairway is called the "stair-head," in contradistinction to the entrance at the lower step, the illustration may be said to give an example of a double-headed stair.

Winding Stairway.—Figure 20—our last example of grand stairways in cut stone—represents a large winding stair in the early Renaissance style in a French castle. In cases like this, if the inner solid or hollow part (stair-spindle or centre-post) be not too small in diameter, the stair will by no means be inconvenient; but the same breadth must be given to the steps in the half-length that rectangular steps have in the whole length.

In all the above examples the staircase—that is to say, the space in which the stair is placed—is elegantly, and even superbly, finished.

Stairs of the Mixed Form, consisting partly of steps with parallel edges and partly of winding steps, although occupying relatively the least space, are inconvenient on account of their irregularity, which, together with their want of beauty, renders them inapplicable to the uses of a grand stairway; such stairs, therefore, are not to be recommended. It is not necessary to treat of back stairs among stone constructions, as they are seldom made of stone, but mostly of wood or iron.

The Perron, or outside stairway, is used only where the ascent is to be made from the street or courtyard to the story of a building lying at a higher level. In public buildings and handsome private residences more ornamental forms of entrance are required, and in other cases simpler forms are selected. The perron in Figure 21 (*pl.* 1) was erected as a portion of the alterations and enlargement of the Hôtel de Ville in Paris, in the Cour d'Honneur, under the direction of Haussmann, prefect of the Seine. It is in the form of a horseshoe of cut stone. In simpler structures and private residences short flights of outer stairs are usually styled "steps." When used for areas or back courts, they are often made of 2- or 2½-inch stone for the tread, the riser being formed of 4½- or 5-inch stone, both tailed into a wall at one or both ends. This is much lighter in effect, and slate is frequently substituted for stone in the tread.

Platforms or Landings of stone are frequently placed over an area before a door, at the head of a flight of stairs, or as the floor of a balcony; they are made from 4 to 8 inches in thickness, according to their extent and bearing. When not constructed of an entire slab of stone, they are made of jointed pieces joggled and plugged together, and are worked on the face and edges as the situation may demand, and should also be very carefully pinned to the walls.

The Geometrical Stairs in stone mentioned above were not represented upon the Plate because, first, they are less to be depended upon, and consequently are infrequently used, and secondly because their general arrangement is simple, although they are difficult of construction. They are most advantageously used in the form of winding stairs, principally because in this arrangement the steps have the greatest bearing upon one another.

Brick Stairs.—Where the proper kind of stone is not to be had, brick stairs may be built in three ways: (1) By imitating the form of the stone steps. Wooden box moulds are used for this purpose, the bricks being set in strong bond with cement-mortar and allowed to stand until the whole has become solid and capable of bearing transportation. (2) By constructing them, in the place where they are to remain, upon a support (boarding) raised a little toward the middle, which is afterward to be taken away; this method of bonding is shown in Figure 22. Cement must here be used as mortar. (3) By building them upon a rising vault, as seen in Figure 23. As by this construction the steps are hollow, the weight is considerably decreased. The steps mentioned in (1) and (2) must be saddled; otherwise, all brick stairs should receive a coating of cement, a casing of wood, or a covering of thin marble slabs.

III. CONSTRUCTION IN WOOD.

This branch of the work will be devoted to the construction of buildings intended for the more common uses, in which the chief material is wood in the form of beams, boards, laths, etc. Timber is reduced to the form of the beam either by hewing or sawing from the tree-trunk, while the other forms, such as planks, boards, battens, etc., are always made by cutting them with the saw from tree-trunks of certain fixed lengths. Spruce, pine, and hemlock are the woods most frequently used in building, but considerable diversity in the practice of the different sections grows out of the relative scarcity or abundance of various descriptions of trees.

Wooden Structures possess great significance in the United States, as the pioneer settlements of nearly all sections consisted chiefly of log cabins or weatherboarded houses; and a large proportion of the existing dwellings that are not located in large cities are made chiefly of wood, because it is the cheapest and most abundant material, and even in many districts where lumber must be obtained from comparatively distant points it is still cheaper than stone or brick. The notable changes to the more substantial and less inflammable materials have occurred chiefly in towns and cities where extensive conflagrations have led either to the legal prohibition of new wooden structures or to their prohibition by the voluntary action of many persons.

Portable Wooden Houses.—The manufacture of portable houses of wood which may be transported in sections, with each part so marked as to designate its place in the finished structure, has become an important industry in the United States. At the present time portable buildings are made in great variety of size and style, many of them being designed with the view of permanent occupation, and the perfection with which all the needful details relating to their manufacture and the assemblage and erection of their parts has been worked out is specially interesting. The field for such portable buildings is very large. There is a constant demand for them from engineers of public works, railroads, canals, etc., especially in regions remote from settlements; they are particularly adapted to the needs of the military service in time of war, when portable barracks, hospitals, etc., are especially in demand; they are also well adapted for the needs of contractors, miners, sportsmen, photographers, camping-out parties, bathing-houses, pavilions, fruit-stands, summer-kitchens, and outbuildings of every description. As above stated, the manufacture embraces not only buildings intended for temporary use, but also more permanent structures having considerable pretension to architectural effect. These larger houses—one, two, or more stories in height—are adapted for summer cottages, and may be obtained of many styles and as elaborately finished outside and inside as may be wished. Other styles of these portable structures are intended for railway-stations, dépôts, storehouses, etc., and may be had of any desired dimensions.

Timber Connections.—The means used for joining woodwork differ entirely from those employed in stone construction. These means consist principally of iron clamps, bolts, screws, spikes and nails, and wooden pins or treenails; otherwise, wherever wood is employed in the form of beams or posts in the regular framework, the separate timbers are chiefly brought into close connection by the insertion of the one into the other to a greater or less degree where they come in contact.

Scarfing.—In their different connections the timbers may meet in the direction of their length or at an angle, or they may cross one another. Figure 1 (*pl.* 3) gives an example of a joint of the first kind, the so-called "oblique scarfing" with notch and wedge. This joint is so arranged that after driving the wedge between the small indents the parts cannot be separated in any direction. In other respects the Figure is self-explanatory. Figures 2 and 3 (*pl.* 3) exhibit square halving, applicable where two timbers cross at a right angle (*fig.* 2) or at an acute angle (*fig.* 3) and are to lie flush with each other and not project. It need only be added in reference to Figure 3 that, to prevent turning, this form of scarfing is provided on the upper surface with small triangular notches at each side.

Dovetailing.—Figure 4 exhibits what is called "dovetailed mortising" for timbers that are to remain flush and that meet at an angle, generally a right angle. The dovetail is so made that it can be lifted out, but not pulled apart, while the breaking off of the dovetail is prevented by an additional notch let in at the top. Figure 5 is a shouldered tenon applicable for the same purposes as Figure 4, but with the difference that the tenon is prevented from leaving its place by the introduction of a wooden pin. Figure 6 exhibits a dovetailed corner-joint, the shape of the notch portion (somewhat hook-like) preventing the solid part from being displaced in either direction.

Cogging.—Figure 7 shows the various forms of cogging used for timbers that cross one another without being let in flush, but are merely notched; the cogs at *a*, *b*, and *c* are called respectively side, middle, and cross cogs. The overlying timbers—not given in the Figure—must be made to correspond in notches, so as to bring the floors of both in contact, and to prevent displacements in either direction. The joints in Figures 8 and 9 are end coggings. Figure 8 shows the dovetailed form, and Figure 9 the form of the side cog.

Mortise and Tenon.—Figure 10 shows the common mortise and tenon used where vertical and horizontal timbers meet. A pin serves to prevent displacement. The breadth is about one-third that of the timber. Figure 11 is a so-called "slit tenon," chiefly used on the upper ends of rafters. Figure 12 shows the oblique tusk tenon used where struts are set into horizontal or vertical timbers. The cut for the mortise extends over the whole breadth, and is intended to prevent the splitting of the tenon, taking up, as it does, chiefly, the thrust of the strut.

Besides the joints which have been shown, various other forms are met with in practice, but they may be regarded merely as modifications of those above described.

Purposes of Joints.—The principal purposes served by joints are lengthening ties, struts, and beams, supporting beams on beams, plates, and posts, connecting struts with ties, and using them as joints for ties and braces. Much depends upon the skill displayed in arrangement and in selecting particular forms for the accomplishment of various purposes. An English writer forcibly observes that simple joints are much more likely to be securely made than more elaborate ones. Scarfing is one of the most common methods, but for important purposes it is considered inferior in reliability.

Principles of Construction strongly recommended include the following: (1) To cut the joints and arrange the fastenings so as to weaken the pieces of timber as little as possible; (2) To endeavor to place each abutting surface in a joint perpendicular to the pressure it has to transmit; (3) To proportion the area of each part of the joint and fastenings to the maximum stress it has to resist; (4) To form the joints with reference to the greatest attainable avoidance of the shrinking and expanding of the wood; (5) To form and fit the different parts of each joint so as to spread the stresses with approximate uniformity over the sections of the timber and fastenings composing it; (6) To make special efforts to devise safeguards against careless workmanship.

Methods of Making Joints.—Of the methods or tools employed, it is stated that in scarfing, cogging, and notching the shoulders are cut in with a saw, but the cheek is generally struck out with a mallet and chisel or an adze. Tenons should be made entirely with the saw, which is also used in cutting wedges. Mortises are frequently bored at the ends with an auger whose diameter equals their thickness, the intervening part being taken out with a wide chisel and the ends squared down with a chisel as broad as the thickness of the mortise. In some cases iron is employed to strengthen wooden joints, and a variety of devices is used in facilitating such operations. They are considered specially advantageous in connection with fished joints, in which the ends of timbers abutting square against each other may be connected by means of fish-plates made either of wood or of iron. When iron struts are used, care should be taken to insure sufficient strength for the purposes they are intended to serve. Uncertainties in regard to this matter induce some skilful carpenters to restrict their use as much as possible, but the growing scarcity of timber and increasing cheapness and abundance of iron and steel, together with the increase of facilities for testing all classes of metallic building material, will presumably extend the use of iron straps, stirrup irons, and iron tie-rods.

Timber Walls may be erected either like stone walls, the wood being used in mass and disposed in layers (log walls), or in the sense of the ordinary frame by erecting frames and filling in the interstices with proper material (brick- and stud-work).

Log Walls.—The construction of log walls (*pl.* 3, *figs.* 13, 14), it may incidentally be remarked, is practised for the most part only in countries where wood is abundant and the climate cold. Figure 13 gives an idea of the projecting ends of the logs, while in Figure 14 the ends are halved and held by wooden pins. The former mode is most frequently employed, the corbel-like projections, as seen also in Swiss houses in the Bernese Oberland, serving for the support of balconies and overhanging roofs. In places where a partition meets an enclosing wall, projections are arranged in like manner. The timbers are not always hewn in a regular shape; on the contrary, the log houses of the settlers in newly-inhabited countries are often made of rough-hewn tree-trunks laid together with notched ends at the corners. It may also be noticed that the joints in all these walls are caulked with some suitable material, and the openings for doors and windows, the jambs of which are formed of posts, receive a casing of boards.

Brick- and Stud-work is either wood alone or is of mixed construction. In the first instance, the framework is made of studs only, with a plate over them, the interspaces being filled in with wood, which, however, is in the form of planks, fitting into grooves in the studs. This kind of stud-work, together with rafter walls, is often to be seen in Switzerland, and was used in the Sigristen house in Marbach, Canton of Lucerne, built in 1809 (*pl.* 3, *fig.* 15). The manner in which these frame buildings are decorated with balconies, overhanging roof, carved work, and painting corresponds to that of the block-houses, as may be seen from the example given.

In frame houses of mixed construction the stud-work is made steady by inclined struts connecting the different members diagonally, the spaces being further divided by cross-bars. These spaces are filled in frequently with bricks united either plain or in figures. In the Middle Ages, and also in the time of the early Renaissance, brick- and stud-work was much used, and the works constructed were often finished in a characteristic manner, as numerous well-preserved examples in Brunswick, Hildesheim, Quedlinburg, Halberstadt, Rouen, etc., prove. The *Alte Wage* in Brunswick (*fig.* 16) exhibits the peculiar character of the mediæval brick- and stud-work—namely, the typical projection of one story over another, a feature which is founded on ideas sound both from the æsthetical and from the constructional standpoint.

The Framework, in which the different timbers are generally made about 5½ inches square, is joined together in every story in such a manner that a sill is notched upon the heads of the joists, which are frequently projecting or resting upon the wall of the substructure. The posts, studs, or uprights, which have their respective distances from one another determined mainly by the position of the doors and windows, are then joined upon the sill with mortise and tenon. Between the uprights, and particularly above and below the openings for the doors and windows, the small cross-bars are then framed in. The plate is placed upon the uprights, the former receiving, in its turn, the notched ceiling joists. In certain parts, particularly the ends, inclined struts and cross-rods are set between the framework, the joists, etc., so as to give stiffness and character to the whole.

Weatherboarded Houses form a large proportion of the dwellings in the United States. A number of ingenious devices have helped to lessen their cost and to contribute to their utility and adornment. In specially cold portions of the Union it has been found advantageous, in some instances, to build a double framework, so as to leave a considerable space filled with air between the outer and the inner wall. It is alleged that by this contrivance less fuel will be required to heat the houses comfortably. English writers commend weatherboarding as safe and economical outside casing for the fronts of dwelling-houses under appropriate conditions, which include separation from adjacent dwellings by a sufficient distance to render the communication of fire impossible, and arrangements for backing up the boarding in a solid manner with brick, stone-work, or rubble and concrete. Where brick walls are built within framed enclosures, care should be taken to secure a convenient relation between the brickwork and the braces used in strengthening and supporting the structure.

Joist Courses.—By a joist course, or joists, is meant a system of horizontal beams lying at fixed distances from one another and arranged between every two stories, or between the upper story and the roof; they are intended to carry both the ceiling of the lower story and the floor of the upper one. Those courses of beams which lie directly under the roof are called "attic courses," in contradistinction to the story courses. In the construction of these courses, it is of the first importance that the injurious sagging of the beams and disagreeable shaking of the floor should be prevented by choosing beams of the proper cross-section. This is regulated by the load to be sustained, by the span, and by the distance of one beam from another.

Supporting-power of Joists.—The load is partly constant (dead load, comprising the weight of the beams themselves, of the ceiling, the floor, and the filling in) and partly variable (live load—furniture, goods, persons, etc.). The former may be calculated exactly; experience is the only guide in estimating the latter. For instance, in dwelling-houses, from sixty to eighty pounds are assumed for each square foot of floor-space; in schools and assembly-rooms, from eighty to one hundred pounds; in storehouses, from one hundred to one hundred and twenty-five pounds.

Span of Joists.—As regards the span of the joists, or the distance between the nearest supporting-points, it is necessary to keep within fixed limits, these being determined by the fact that the supporting-power of the beams does not increase *pro rata* with their own weight. As an average limit for the span, 25 feet may be assumed, the depth of the room not exceeding this save in cases of necessity. The distance of the beams from one another must also not pass a fixed limit, chiefly in order to prevent the floor-boards from sagging; this distance may be from 2½ to 3½ feet, measured from centre to centre of the beams. The joists are given an oblong cross-section, as shown in Figure 17 (*pl.* 3).

If the width of the rooms over which beams are to be laid exceeds 25 feet, a mere increasing of the cross-section will not suffice, but either artificial supports for the beams at various points in their length, consisting of wooden or iron girders or of posts, must be applied, or, if it be the uppermost course of joists, some method of suspension from above may be made inside the attic. This will be treated more fully under Roof-construction. Some help may be had by laying two joists close together and connecting them with "dowels."

The following additional remarks respecting joist courses will be found pertinent: (1) The bearing at the ends of the joists must be at least equal to their height; (2) Wherever possible, the beams are to be laid in the direction of the depth of the room or building; (3) If a chimney or other obstacle occurs in the course of the joist, the latter must be trimmed for it —that is, cut off and connected with the adjacent joists by a beam-trimmer; (4) If a solid wall runs parallel with the direction of the beam, a beam lighter than the rest (wall-beam) is to be set at each side of the wall, provided the latter is to be continued higher up; but if the partition is of framework, the effort should be made to set a beam upon it, so that the beam may act as a cap for the lower partition and as a sill for the upper one.

The Ceilings may be constructed with visible joists, as in Figure 18 (*pl.* 3), or the joists may be concealed with boards or with lath and plaster. The space between the joists should not be left entirely vacant, but to render the ceiling proof against the penetration of moisture, sounds, and cold air, a false floor carrying some kind of solid waste material should be interposed. Figure 17 shows the arrangement of such a false floor, which is slid into the grooves or rabbets in the beams. It may also be rested on strips which have been nailed on.

Ceiling Supports in Wood.—Special supports for ceiling joists are often required, on account of the great width of the rooms. That these supports can be employed in a rich and tasteful manner is shown in Figure 18; it represents the interior of the great hall in the so-called "Gürzenich" at Cologne. Twenty-two columns of oak are connected by light wooden arches whose spandrels are filled in with Gothic fretwork. The effect of the whole is much increased by skilfully-disposed polychroming and gilding. The length of the hall is 132 feet; the average height 46 feet, the span of the centre aisle $43\frac{1}{2}$ feet, and that of the side aisles $11\frac{1}{2}$ and $21\frac{1}{4}$ feet respectively.

Flooring.—In Paris, during a protracted period, much attention has been given to methods for deadening the communication of sound and of fire between different stories of houses or buildings devoted to multifarious purposes and occupied by numerous tenants. A demand for the accomplishment of similar objects has materially increased in American cities since a considerable number of tenement-houses, French flats, and gigantic business edifices have been erected.

The Parisian Method of Flooring differs radically from that generally adopted in other countries. It aims to secure in the solid mass of the walls the support of the girders which sustain the floor, and, while the floor itself is framed, it is said that boarded floors are not to be found in any of the dwellings of Paris except those of the most costly description. Whether the floors are boarded or not, the flooring joists are as completely covered on the upper side with a coating of mortar as the ceiling below is covered with a coating of plaster. In the principal portion of the space adjacent to the joists rough battens are placed as close together as they will lie, and on this foundation, which serves a purpose analogous to that served by laths in interior walls, floor-mortar is spread to a thickness of about 3 inches; and, as a compact combination occurs to a considerable extent in the entire mass between the ceiling and top of the floor, it may be said that different stories are separated rather by a wall than by such materials as usually separate the different stories of American buildings. The result of the Parisian system is a firm floor, upon which paving-tiles are generally laid in ordinary dwellings. The safeguards against the communication of fire and of sound are increased by this additional precaution, and an indestructible floor is provided. In applying large quantities of mortar to the foundations of floors, special efforts should be made to guard against the effects of expansion. Modern practice in Paris in reference to floors is to use wrought-iron joists rolled in I-, T-, and I-forms, and to fill in with strong mortar or plaster. Details will be more particularly described in the discussion of iron structures. In some cases, to lighten the aggregate weight of the structure, earthen pots have been placed between the joists, and the spaces filled with mortar.

Roof Construction in Wood.—The word "roof" is used to express the covering that is designed to protect the interior of any building from the weather. In carpentry the term "roof" is restricted to the framework upon which an external coating is secured, which in large buildings is perhaps the highest triumph of applied science displayed in the edifice.

Considerations in Roof Planning.—The means of supporting this outer covering of roofs is the chief consideration in their construction, and in making the plan it is in the first instance necessary to decide upon the general form and the angle at which the surfaces should stand; in the next place should follow the consideration of the construction of the timberwork which serves as the support of the covering itself, the boarding, the dimensions, particularly the depth of the building, the dimensions of certain of the inner apartments, the position of such inner walls as have a modifying influence, etc. Framework in timber has until the recent substitution of iron been almost the only method of forming roofs, and the object has been to arrange the timbers so as to combine the greatest strength and stiffness with the least weight of material, avoiding lateral strain or thrust upon the supporting walls, and so as to present two or more inclined planes for the slopes of the roof over the enclosed space.

Forms of Roofs.—Roofs in general, notwithstanding the great variety in shape and appearance, may be reduced to two kinds—the lean-to and the saddle roof. The simple form known as the "lean-to," or shed roof, was primarily constructed by merely laying pieces of wood across in the position of an inclined plane, in order to throw off the water. Both of these classes of roof may, however, when presupposing the simple right-angled ground-plan, terminate at the sides by gables, or be hipped—that is, sloped—on the narrow sides. Figure 19 (*pl.* 3) represents the saddle roof with gables at the sides, the gable in the middle not being taken into account. The line at the top, which is common to both surfaces, is called the "ridge" of the roof. In Figure 20 is exhibited the example of a simple hipped-saddle roof erected upon a right-angled ground-plan. It shows four oblique lines of intersection or hips, besides the ridge. The slopes are triangular surfaces, while the others have the form of the parallel trapezium. Figure 21 (*pl.* 3) shows the pavilion-roof, a special form of the hipped roof suitable for square or polygonal ground-plans. All the connecting roof-surfaces are triangular. Steep roofs of this class, when erected upon towers, are usually called "spires." Figure 22 represents a flat-topped roof which might be described as formed by cutting off a sloped or hipped roof horizontally. All the surfaces have the form of the parallel trapezium. The platform is not made perfectly horizontal, but is provided with a slight fall on each side; it is used either to lessen the height of the roof without altering the angle of inclination of the surfaces, or, in the case of an irregular ground-plan, to conceal that irregularity, which is then communicated to the platform only. Figure 23 shows the simple lean-to roof with no side slopes; this form is generally used in cases where a building stands with its long side close to a party-line. Figure 24 presents a mansard or broken (curb) roof with a hip-slope. The surfaces here appear broken—that is, the lower portion of the roof is considerably steeper than the upper—a moulding or projection being placed where the two surfaces meet.

Other Forms of Roofs.—Besides these varieties, there are roofs with curved surfaces, domes being included in this class. There are also composite roofs, which are erected over more complicated ground-plans, particularly plans with projecting angles, every angle occurring in the ground-plan having the effect of making a valley in the roof—for instance, such a valley as is seen in Figure 19—arising from a projection of the building.

Angle of Inclination of Roofs.—In considering the angle of inclination in roofs, it is generally assumed to be the same throughout the same structure, depending chiefly upon the character of the covering material, but also with due consideration to the position, the style, and the purposes the building is intended to serve. It should also be stated that it is not usual to regard the inclination of the roof as a question of degrees, but rather with reference to the fitting proportions necessitated by the relative heights of the roof and the depth of the building, the saddle roof being always presupposed. In cases where tolerably good tiles are used as covering material, the inclination may be estimated at from one-half to one-third of the depth; with tiles of good quality, the proportion may be from one-fourth to one-fifth; with slate, from one-fourth to one-sixth; while with tarred felt or similar roofing material, as well as with metal, the slope may be less steep. In all forms of timber roof construction, it is important to overcome the thrust proceeding from the oblique position of the roof and to prevent displacements in the longitudinal as well as in the transverse direction; these results are generally attained by triangular connection.

Roof Construction.—Timber roofs are constructed in the most varied manner; for the purpose of this sketch the methods employed will be confined to the more usual systems and to a few characteristic examples. It is understood that the saddle roof only is referred to. As a rule, the support of the material of the roof—or, rather, the immediate support—is effected by inclined timbers or rafters, but occasionally this duty is performed by horizontal timbers, or purlins. These rafters either stand directly on the attic joists or the joists may lie lower than the ends of the rafters. By lowering the joists, as in Figures 26 and 28 (*pl.* 3), the construction, it is true, becomes somewhat more complicated, but in another way some advantages are gained. Among these may be cited the ease with which the space in the attic may be utilized in avoiding the useless angles of the roof; there is also a decided gain in the decreased slope of the roof, and also an increase in the height of the façade, etc. No essential difference in the system of construction results, however, from this lowering process, while a difference does result from the manner in which the attic joists are supported or sometimes omitted altogether.

Roof-trusses.—This brings us to the subject of trusses, which may be classified as follows: (1) Roof-trusses with sufficiently-supported attic joists; (2) Roof-trusses with suspended joists; (3) Roof-trusses without joists.

(1) *Roof-trusses with Sufficiently-supported Attic Joists.*—If the entire depth of the building is not more than 25 feet, the beams as well as the rafters will require support only at the ends. Each pair or brace of rafters is secured at the apex by mortises and pins and is tenoned into the joists below, with which it forms a triangle and a so-called "roof couple." These couples are set at a distance of from 2½ to 4 feet. To prevent displacements lengthwise, "storm braces" are nailed obliquely upon the lower side of the rafters. In steeper roofs each two rafters are joined together for half their length by a horizontal timber mortised in and called the "collar beam." If the depth of the building is more than 25 feet, "standing-posts" are introduced, which may be either vertical or inclined.

Standing-post Roofs.—The characteristic point in standing-post roofs is that the separate main couples have posts which are mortised into the attic joists and carry purlins proceeding along the length of the roof; these, in turn, take up directly either the rafters or the collar beam of the rafters. The rafters are then notched down to the purlin. For the prevention of longitudinal displacements, struts are used, being mortised in obliquely between the purlins and the posts. In the simple standing-post roof there is in each main couple but one post, which, as a rule, extends up under the ridge beam. The simple post roof will answer for buildings having a depth of from 25 to 33 feet; the attic joists must in this case be supported by a wall, or by something similar, at least once in the course of their length.

In the double standing-post roof (*fig.* 25) there are posts in each main couple, either with a collar beam, as is shown in the left side of the figure, or without one, as on its right side. In the latter case a "straining piece" is used, but of course only in the main couple, and it is placed between the purlin and the posts, which are connected with the latter, as in the Figure, by a corner-brace, and halved with the rafters.

The Oblique-post Roof (*fig.* 26) has inclined side-posts, which, in the case of the collar beam here represented, carry the purlin above, and, being mutually connected by a horizontal timber, the straining piece, are further stiffened by oblique braces. The left side of the Figure exhibits this arrangement. The oblique post without collar beams is shown on the right. Here a connecting strain-piece rests first on the post, and upon the former, in the angle with the rafter, the purlin. Both portions of the Figure show also the "sunken-joist course," which may be applied in like manner in the double standing-post roof. The double standing- and oblique-post roofs are suitable for buildings with a depth of from 33 to 46 feet. The former style furnishes a more solid kind of construction, while the latter affords the advantage of a more open and unobstructed floor-space. For buildings with a depth greater than 46 feet, there should be used either the combination of the single standing- with the double standing-post roof (triple standing-post roof), or the combination of the single standing- and the oblique-post. In both cases the middle post must be placed under the ridge beam.

(2) *Roof-trusses with Suspended Joists.*—The suspension of a beam—that is, its support from above somewhere in the course of its length—may be either throughout its entire length, if there be no other support inside the building from below, or only upon a more than usually large free-lying part of the beam. The suspension itself may be either single, double, or compound.

Single Suspension-truss.—The roof-truss in Figure 27 (*pl.* 3) represents an instance of single suspension, the beam at its middle being fastened to a suspended post which, in turn, is held by the oblique timbers directed toward the supported ends of the suspended beam. The suspended post (king-post) takes the place of the standing post, and thus appears only in the main couple. The rest of the ceiling joists are held by girders fastened above or below the tie beam; if not, as assumed in this diagram, the joists, as they run lengthwise of the building, are fastened directly to the tie beam, which serves as a girder. The ceiling joists are hung to the tie beam by screw-bolts. If the rafters are to be again supported at any point in the course of their length, the necessary purlins, as the Figure shows, are to be laid on a horizontal double straining-piece, which is bolted to the inclined struts and to the post. The simple king-post roof is suited for depths of buildings that do not exceed 32 feet.

Double Suspension-truss.—Figure 28 shows a roof with two suspended posts (queen-post roof) and "sunken joists." The support of the ceiling joists is effected by girders lying upon the tie beam at the foot-end of the queen-post. Besides the inclined struts, we have here also the straining beam, which serves to resist the pressure made in the inclined pieces against the posts by the suspension. In other respects the queen-post roof is treated in a manner corresponding to the double standing-post roof, and, like the latter, is suitable for depths of buildings of from 32 to 46 feet.

Combination Suspension-truss.—Figure 29 gives an example of three suspended posts (combination of king- and queen-post roof) built over the apartments, meeting at right angles, a point in the construction being that, instead of a full-joist course, tie beams only are present; so that the girders above and below are not necessary. The illustration represents the construction of the roof-truss in the basilica which Vitruvius, who lived in the time of the Roman emperor Augustus, projected for the Julian colony at Fano, and described in his work *De Architectura*. It has been restored by Viollet-le-Duc, partly from such ruins of the basilica as could be depended upon as guides, and partly from the brief descriptions of Vitruvius. The span is 58½ feet. The triple-truss frame is suited for depths of buildings from 46 to 65½ feet, and is formed, as the illustration shows, by combination of the single with the double truss, it being necessary here to construct the truss-posts of the latter of two timbers laid together and bolted.

Truss-frames over different portions of the beams will not require any particular description or illustration after what has already been said; it may be stated, however, that in some cases truss-frames are also arranged lengthwise with the roof.

(3) *Roof-trusses without Joists.*—When a closed attic is not required and the view of the roof construction does not interfere with the manner in which the room is utilized, the roof beams proper may be omitted entirely, or, as Figure 30 (*pl.* 3) shows, the tie beam alone may be used, the former being resorted to chiefly in those cases where the interior is to be kept, as far as possible, open, like a hall. The interior here is required not only to uphold the roofing material and its support, but also to resist the thrust of the roof upon the enclosing walls to the greatest practicable degree. This is effected either by the suitable connection of long timbers, or by the aid of iron rods or cables, or, finally, by plank rafters.

Figure 33 shows the roof-truss constructed by Von Moller over the riding-school at Wiesbaden. Purlins instead of rafters are used in this case for supporting the roof material. They are secured at certain places to a sort of rafter. The latter are, in turn, so supported by various struts, which cross one another and are partly doubled, and also by a horizontal double tie, that the thrust upon the enclosing walls is almost overcome.

The method of construction shown in Figures 31 and 32 is the one employed in the Sängerhalle, built in 1865 at Dresden. This will be referred to when describing Plate 19. The peculiarity of this roof-truss, constructed by the architect Edward Müller of Dresden, consists not only in the use of lattice-rafters composed of stays set together and purlins spanned between to support the weaker parts (*fig.* 32), but chiefly also in the combination with pairs of wire cables, which, suspended to large poles, proceed diagonally downward and are finally fastened in the earth. To provide against any injurious side-thrust, a counter-cable connecting the lower ends of the lattice-rafters is also used. The span of the roof-truss between the large poles is 148½ feet; the distance between every pair of main-couples is 33 feet.

Roof-trusses with Plank Rafters, the details of which are shown in Figure 33, are not always used without roof-beams, but the latter are at least not to be regarded as an essential part of the roof-truss, for the plank rafters, on account of their construction, exert but little horizontal thrust upon the enclosing walls. The characteristic point in this construction, which was used first by the French architect Delorme as early as the sixteenth century, consists in the fact that from three to five layers of short arched planks are nailed together, with broken joints. They thus form arch-ribs of great stiffness and resisting power. The joining in the length consists, as the Figure shows, of horizontal pieces mortised in and bolted on the upper and lower sides of the rafters, as well as wedged in by the pieces running through them. These plank rafters are chiefly used in the construction of roofs with rounded surfaces, particularly cupolas, the material intended to serve as a support to the roofing material being brought directly in contact with the plank rafters. An interesting example of this class—in which, also, the illustration given belongs—is the cupola, 110 feet in diameter, of the Catholic church at Darmstadt built by Von Moller.

In the three systems of construction which have been already discussed, the simple saddle roof alone has been under consideration, and the dome is mentioned only in the last example; space does not permit the treatment of roof-trusses for other forms—namely, the platform, hip, pavilion, mansard roof, etc., for which the reader is referred to the numerous special works on carpentry and building.

Wooden Stairs.—In large mansions, and in other situations where elegance and convenience are the chief objects of consideration, winding stairs are never introduced when it is possible to avoid them. The best architectural effects are produced by the use of rectangular stairways with ornamental railings and newels. In structures of the Gothic style, no other kind can be introduced for a principal staircase with propriety and harmony of design. Modern architecture, however, admits of great latitude in this respect, the stairway frequently ending in a circular form, and the railing continued, beginning from either a scroll or a newel. When there is a wall at each end, the stairs are merely built in at the time the edifice is constructed; but if they are supported at one end only, they are styled "geometric" stairs, and depend entirely on being securely wedged into the wall, as they rely solely for stability upon the wall and the support which each derives at one edge from the step below. If square in section, they are styled "solid" steps; but, as the under side, or soffit, is then irregular, it is usual to make the steps somewhat triangular in shape, so as to present a continued soffit. In this case they are styled "arris," or "feather-edge," steps. Care is required that there should be no sudden or irregular changes in the curves.

The rules governing the ratio of ascent in stairways, and also the general styles of construction, have already been considered in the section devoted to the description of stone stairs, and the same remarks apply to the erection of wooden stairways. In respect to the construction of the latter, attention need be bestowed only upon those which are composed of posts and boards, for the reason that those formerly built of beams, after the manner of stone stairs, and known as "block stairs," have become practically obsolete, on account of the great quantity of wood necessary to their erection and the serious danger from fire consequent upon their use.

Supports and Steps.—Wooden stairs obtain their support from "strings," the steps being either housed in (*pl.* 3, *fig.* 34) or saddled (*fig.* 35). The former plan is the more generally employed. Each step consists of a horizontal portion, or tread, and a vertical portion, or riser. The former is usually made from 1½ to 2 inches thick, and the latter from ¾ to 1 inch, while the thickness of the strings is from 2 to 3½ inches, according to their length and the size of the stair. In stairs with housed-in steps, the latter are set into grooves from ¾ to 1 inch deep, which correspond to the step profile, while in those with the saddled tread the strings are to be cut out above, in accordance with the tread and riser, which are then screwed on. For the rest, as regards the form of the string-boards, they are straight in stairs having a straight flight, but in the case of winding stairs, as in the illustrations, they are curved once when the ground-plan has straight borders (*fig.* 34) or are double curved if the borders are curved. These curved string-boards are used also where the stair does not wind around a column or spindle. Such a curved piece is shown in elevation in Figure 34*a*, and in ground-plan at *b*. All curved string-pieces must be cut out of the timber beam, and the pieces must be connected by screw-bolts at the joints, which are generally vertical.

Doors and Windows.—Considerable ingenuity, intermingled with a number of modern improvements, has been displayed in connection with the construction of doors and windows. At early stages of erection provision must be made for the apertures in which they are to be placed, and the proper performance of this task forms an important feature of the labors of builders. Doorways are fitted with jamb linings and architraves, or pilasters.

Doors hung in two equal widths and to the opposite side posts of jambs of the frame are called folding-doors, or double-margined, and they are necessarily similar. They are most frequently used in the interior construction of dwellings and the entrances of relatively large edifices. Partly for ornamental purposes, but more especially to reduce to the lowest attainable point the inconveniences arising from shrinkage—which is one of the greatest defects of wooden material—doors are panelled to the extent of using two, four, six, eight, or in some cases even ten, panels. Considerable care is requisite in hanging a door in the best manner. Special efforts should be made to establish a proper relation between the door and the hinges, as it is necessary that the various parts should be accurately fitted; otherwise, movements will be obstructed and the hinges injured. One of the difficulties is to make doors clear a carpet and yet be close to the bottom when shut. The best method of avoiding annoyance from this source is to attach a piece of wood about one-fourth of an inch thick to the part of the floor immediately under the door when it is shut. The successful working of doors may be facilitated by the use of various forms of improved hinges, one of which is known as the rising, or skew-but, hinge. It is so arranged that if more than half opened the door goes to the walls, and if less than half opened it closes itself.

Windows.—The arrangement of windows, sashes, shutters, and shutter fastenings has been subjected to a number of variations. In English nomenclature the upright sides of the outside frame of a sash are designated "styles," and the transverse or horizontal parts are called "rails." The inner framework or divisions for the panes are called "upright" and "cross" bars, but the latter titles are subject to modifications based on variations in moulding. Sashes are either hung upon hinges or hung with lines, pulleys, and weights. When hung with hinges, they are usually called "casements." Sashes hung with lines require cased frames to receive the pulleys and weights. In the arrangement of sash-frames great accuracy and skilful workmanship, as well as the selection of superior material, are necessary to produce satisfactory results. There are few things in dwellings more subject to decay, disorder, and disarrangement than appliances used in lowering and raising windows.

In constructing sash-frames the sill is generally made of durable material; the sides are made of boards grooved to receive a parting bead; the ends of these boards are fixed into the upper surface of the solid sill below, and into a board parallel to the sill which forms a head above, and they are called "pulley-pieces" because they receive pulleys let into them near their upper ends. Linings are nailed on the edges of the pulley-pieces and to the sill and head above and below, inside and outside. The casing is completed by fixing thin linings on the outer edges of the outside and inside linings, parallel to the pulley-pieces, to prevent obstruction to the free movement of the weights, and devices are adopted for facilitating the convenient removal of sashes. The fitting of sashes is postponed until the frames are immovably fixed, for the purpose of making due allowances for inaccuracies in the frames. After the sashes are fitted, a plough-groove of proper dimensions to receive the sash-line is made in the edges of about two-thirds of the length of the styles. Subsequently a sash is weighted; two weights are selected which together nearly amount to a counterpoise, and by either of several methods the sash-line is attached and arrangements are completed for conveniently raising or lowering the sash.

Window-shutters are usually framed in a style corresponding to that of the doors and other framed work of the room to which they belong. A variety of methods of constructing, fastening, and arranging shutters has been adopted, and details are subject to numerous changes from time to time in many localities.

Bell-frames are structures designed for the support of bells. Formerly they were invariably made of wood, but now they are frequently constructed of iron. For the wooden bell-frame, an example of which is given in Figure 36 (*pl.* 3), it may be remarked that good well-seasoned timber is absolutely necessary, and the whole joining must be so carried out that no displacements nor sagging can result from the swinging of the bell. The shape of the bell-frames must depend upon the number of the bells and the manner in which they are arranged, as well as upon the very limited amount of space that can usually be devoted to them in the towers in which they are erected. In making them, the builder avails himself of sills, posts, plates, braces, and struts, as in other works of carpentry. These pieces—which are not only mortised together, but are also bolted and armed with iron at the joints—form collectively the frame for the support of the heavy wooden bell-yoke, which rests in sockets. The beam is generally composed of two or three timbers fastened one upon the other by iron straps and dowels. The bell itself is fastened to the yoke by strong iron bands. On the lowest part of the beam are the iron trunnions, resting in collars, thus enabling the bell to be turned or swung. Many plans have been proposed for obviating the injurious effects of the swinging of the bell, the best being to bring the suspension as nearly as practicable above the level of the trunnion, thus obtaining a more elevated position for the centre of gravity of the bell by the use of an iron yoke turned upward in a curve. Figure 36 (*pl.* 3) is taken from Romberg's work *Die Zimmerwerks-Baukunst*, and shows the bell-frame in Saint Thomas's Church at Leipsic.

IV. CONSTRUCTION IN IRON.

Wrought iron and cast iron are coming more and more into use in building construction, not only as accessory materials for making nails, bolts, etc., but also for the construction of independent parts of buildings and of entire edifices. At present attention will be confined to the consideration of buildings in which iron plays the principal part. But before proceeding to this branch of the subject it will perhaps be better to devote a few words to the manner in which the several portions of the iron-work are united. This union is effected by two distinct methods, to one of which belong riveting, soldering, and welding, while in the other are comprised the joinings made by the use of screws and wedges.

Methods of Uniting Iron.—Riveting is preferred for wrought iron, for which material it is used exclusively, while wedging and soldering are used for both wrought and cast iron, and screws especially for cast iron. In riveting, the joining, particularly of plates—for example, boiler plates—is effected by rivets, which are short wrought-iron pins with a conical head on one end; these are passed through the rivet holes in the pieces to be joined, an additional head being formed on the plain end of the pin by hammering after it has been set in place. Soldering consists in introducing another metallic substance, in a melted state, between the surfaces to be joined, which must be quite clean. Pure copper affords the best solder for iron. Welding consists in heating red-hot the portions to be joined and uniting them intimately together in this condition by hammering. When pieces—for instance, two plates—are to be connected by screws, use is made of a screw-bolt with a nut and head, the nut being set on and tightened up with the wrench. As in riveting, the pieces to be joined must have suitable holes pierced through them before they are screwed together. Wedging, where the pieces which have been slit are held together by wrought-iron wedges driven in, is more used in machinery than in building. Finally, it may be added that in these iron joints, just as in woodwork, the ends of the pieces may be fashioned in such special ways as will best insure a firm and solid connection. In iron- as well as in woodwork, scarfing, forks, dovetail, tenons, etc., are employed.

Beams and Girders.—As in the case of free-lying wooden beams the oblong cross-section stands in relation to the sides as 5 : 6, so in the case of iron girders the I-shaped cross-section is the best, so far as regards the least relative consumption of material. Other forms of cross-section—as, for example, the simple T or the U—are used only in exceptional cases for free-lying beams and girders. Beams and girders of this description may be cast, or, if they are to be of wrought iron, may be rolled, or may be made of vertical and horizontal plates riveted together with the aid of angle-plates, or, finally, by riveting together single rods crossing each other and having horizontal top and bottom plates (lattice girder), also with the aid of angle-irons. The dimensions of the cross-section of all such girders will depend not only upon the material and the method of manufacture, but chiefly also upon the special purpose to which they are to be applied, and upon the stress to which they are subjected.

Iron-joist Ceilings.—In the construction of flat ceilings, iron beams are more employed as girders for wooden beams, though they also may serve the purpose of the ceiling-joist proper; but in vaulted ceilings they supply the place of the separating and supporting ribs of the transverse arches. Figures 1 to 3 (*pl.* 4) show cross-sections of a number of ceilings, as constructed in Paris, with iron joists. The joists, made of rolled iron, here receive a camber of $\frac{1}{200}$ and a depth which must not be less than $\frac{1}{36}$ of the span. In the construction shown in Figure 1, first between the joists, that lie about 2½ feet from one another, and upon their lower flanges, are laid square iron rods about ½ inch in thickness and at distances of from 2½ to 3 feet; upon these are then set flat iron rails parallel with the joists and fastened to the square rods by wire, and upon these rails comes a course of hollow bricks, as is shown in the Figure. Finally, a layer of mortar or plaster is poured over the brickwork, which then receives either a stone flagging or a wooden floor. The ornamental plaster-work of the ceiling, of plaster of Paris, is poured upon a planking before the setting of the bricks, this planking being removed after the mortar has dried.

Figure 3 (*pl.* 2) exhibits various forms of hollow blocks of hard-burnt fireclay and terra-cotta, which are much in vogue at present in the United States in the building of important structures designed to be fireproof. According to their form, these are designed for the construction of flat and segmented arches between iron girders and wooden beams. They serve a useful purpose also for partitions, furring for walls, linings for flues, columns, etc.

Figure 2 (*pl.* 4) shows a system in which hook-shaped iron rods about ½ inch thick are hung at distances of about 2½ feet between the joists, which lie from 2½ to 2¾ feet from one another. This is seen in perspective in Figure 4 (*pl.* 4). Here again we have bars parallel to the joists, and upon the network thus formed is a layer of mortar about 2½ inches thick, which is supported until it has set. When a wooden floor is to be laid, wooden sleepers are notched upon the beams, as is seen in the illustration. The system shown in Figures 3 and 5 resembles the preceding, except that here the iron cross-bars are run through and bolted inside the iron bands encircling the joists.

Vaulted Ceilings.—When iron girders are used to replace the transverse arch in vaulted ceilings, the vaults, generally made of hollow brick, are supported upon the lower flanges of the girders. The cavities thus formed are then bricked up to the upper edge of the girder. The superior advantage offered by iron girders over the transverse arch consists in there being no thrust upon the walls, and, moreover, there is a gain in height. Constructions of this kind on a great scale are often seen in large factories. The example given in Figure 6 is the interior of the Joint-stock Spinning-works at Chemnitz, in which the girders, made of plates riveted together and braced by horizontal round iron tie rods, are intended to support the vaults.

Iron Columns are hollow castings. The diameter and thickness of the metal must depend upon the height of the columns and the weight to be supported. As a rule, the inside diameter is four-fifths of the outside. Particular attention must be paid to the manner in which the lower ends of the columns are secured. It is advisable to screw down to the stonework an iron plate cast for the purpose, and upon this to fasten the foot of the column either with screws or, at least, by rebating. The manner of securing the upper end will depend upon whether another column is to be set over it. In this case, which is also seen in the form of construction exhibited in Figure 6, a connection will be necessary between the columns that are set one over another, and it must be made either directly or by connecting pieces. If necessary, the broad bottom plate of the upper column may be set upon the broad top plate of the lower. It need hardly be said that the girders supported by the columns are to be secured to them by flanges, bolts, etc.

Iron Roof Construction.—In modern times iron has been much used for roofs and roof-trusses, particularly where safety from fire and great solidity, combined with light appearance, are desired. For very wide spans without intermediate supports, iron is exclusively employed, as in such cases woodwork is not only very clumsy and complicated, but is also always untrustworthy, and generally more expensive. Iron roof construction may be classified in two divisions, as follows: (1) That with complete attic framing, where an attic space is to be obtained; (2) That without attic framing, where no attic room is required. Roofs of both these varieties are constructed either of iron alone or of iron and wood combined; also of cast or wrought iron in the iron roof proper, and of the two combined. The system of construction here, as well as when wood is employed, will be much influenced by the form of the roof. Reference is made here more particularly to the saddle roof.

Attic Framing.—As regards roof construction of the first kind—that is, with the attic and the iron framework necessary in this system—the best plan, but suitable only for small spans, is to fit cast-iron shoes on the ends of the I-beams, or to screw them on, and into these to set iron rafters united at their upper ends by bolted or riveted plates. The beam in this case takes up the entire horizontal thrust of the roof. When the span is greater, additional supports are placed at various points throughout their length under the rafters, so as to avoid too heavy cross-sections; they should meet the joists only when they are directly supported from below, if the ceiling joists are not to suffer from an improper distribution of the weight.

Chemnitz Spinning-works.—An example of attic construction on a large scale is given in Figure 7 (*pl.* 4), which represents the spinning-works at Chemnitz. Reference has already been made to the construction of the girders and columns in this building. Each rafter in this case has a direct double support from below; besides, there is a sort of iron collar-beam introduced higher up which contributes to the stiffening of the rafter in the same manner as each of its supports. Round iron rods are used to connect the rafters along the length of the roof; these are arranged in pairs, one above the supports and one in the crown of the roof. To prevent displacements, crosses of round iron are laid along the length of the roof between each pair of supports, as seen in the Figure. The iron ceiling joists, each composed of four parts spliced together, are supported in their length on three points of the joist, partly in a direct manner by iron columns and partly by "reverse truss-frames," which proceed lengthwise and rest upon the columns by their ends, and consist, each, of a horizontal tie beam, two small posts, and three tension rods. The Figure also shows these accessory constructions, which are largely employed in other works.

Suspension Framing.—If the ceiling joists cannot be directly supported in their length from below, the only other resource will be to use suspension from above; but this is seldom seen, because these joists are mostly used in the roofing of halls and hall-like apartments in which there is an attic space, and consequently no necessity for special arrangement of the ceiling joists. This system, forming the second class indicated above, is now very largely used, and may be subdivided into such as have (1) Trussed frames; (2) Arch-ribs set below; and (3) Flat or curved lattice rafters.

Trussed Frames.—Two examples of roof construction of the first class, where the horizontal thrust is taken up by tension rods, will be found in Figures 8 to 14 and 15 to 21, together with the necessary details. The first example shows the roof construction with truss-frame according to the system of Polonceau, as used in the Market-Hall at Nancy; the second shows one of the same variety with truss in crescent form, as used in the great hall of the Central Dépôt at Birmingham.

The simplest case of roof construction with iron truss-work is that in which two iron struts having on their backs the purlins for the roofing material or for the rafters are connected directly together above, while a horizontal round tension rod is applied below. Trusses of this kind are generally placed at distances of about 13 feet from one another, and are further arranged according to the position and size of the window piers. If, because of a large span or to avoid too heavy sections, it seems necessary to give the latter additional support in their length, it can be done in the manner first suggested by the French engineer Polonceau, as seen in Figure 8 (*pl.* 4)—namely, by arranging the work so that the keel of each of the two short supports of the principal struts shall be connected with the solid apex of the latter by round iron suspension rods. The chief tension rod in this case must consist of several pieces.

The shapes of the individual parts of these constructions, their manner of connection, and the auxiliary pieces, will be seen among the details (*figs.* 9–14) belonging to Figure 8. The main struts are made with the I-shaped cross-section, although their having to resist pressure in their length must be taken into consideration, notwithstanding the fact that the cross-shaped section is better fitted for the purpose; this is done to make more convenient connections with other parts and for the reception of the purlins. The struts are easily made by rolling; the supports of the main braces, on the other hand, which likewise have to sustain compression, are generally made with the cross-shaped cross-section. When the length is not great, cast iron may best be used, or for somewhat longer ones four rolled and riveted angle-irons. The tension and suspension rods, like all that are to be subjected to tension, are made of round wrought iron.

Where the length is somewhat great, these rods, particularly the horizontal ones, must be provided with some arrangement for regulating their length. On account of the dividing of the rod which thus becomes necessary, a light tension rod to prevent sagging is generally used. Figure 8 shows this arrangement with the tension rod in the middle. Figure 12 represents the detail, *a* being the elevation and *b* the plan. The two divisions of the tension rod are inserted into a sleeve-nut at the two sides, with oppositely-directed screw-threads, while the rod goes through vertically in the middle and finishes with an ornamental screw. This rod is hung between two short iron beams above by screw bolts, as shown in Figure 10, the rails, in their turn, being hung on a packing-plate connected with the main braces.

The most important connecting pieces in roof construction with trussed frames are at the points of meeting of the tension and suspension rods with the support of the chief braces. Figure 11, *a* and *b*, shows one of these connecting pieces in elevation and plan as generally used—that is, so that the individual rods and the support are attached between two wrought-iron plates by means of short bolts. By this method of connection, a slight movement of the rods becomes possible in the event of such changes in dimension as are caused by variations in temperature. For this reason, also, the connection between the braces and tension rods is not stiff, but loose; here a fork is used, which encloses the brace or cast-iron shoe, separately shown in Figure 10 (*pl.* 4). This belongs to the same with its open part, its solid portion receiving the end of the tension rod, which is provided with a nut and thread. Sometimes a fork is placed on the rod, as on the upper ends of the diagonal suspension rods in Figure 10.

As regards the first example (*fig.* 8) of suspension-truss construction, we may mention that the span in the clear is 39⅓ feet, that the upper part has a lantern for ventilation supported by cast-iron columns, and finally that the purlins carrying the rafters are of wood and are fastened upon the iron struts, as seen in Figure 14. The ridge purlin alone is made of iron, and this rather serves to strengthen the suspension trusses in the length, and therefore does not lie over the braces.

Bowstring Truss: Birmingham Railway-station.—The second example, Figures 15 to 21, exhibits the details of the iron-truss roof of the Central Railway-station in Birmingham, England, and is an instance of the "bowstring truss"—a system quite different from the foregoing. A girder made of one vertical plate 15 inches wide, with four angle-irons and of circular form, takes the place of the braces; Figure 16 gives the cross-section of such a girder at its ends and middle. The purlins lie over the iron girders, while underneath them a system of vertical supports and diagonal ties connected at their heel by the suspension rods, 4 inches thick, is arranged so as to stiffen the whole. All the single ties and plates have stiff joints, the connection being made partly by riveting, as seen in the detail of the Figure, and partly by bolts; thus collectively they form an immovable framework that spans a hall 208 feet in width.

This framework (*fig.* 15) rests at one side upon the wall of the dépôt-building, where it is bolted down; on the other side it rests upon hollow cast-iron pillars, whose upper ends are seen in section in Figure 21. To prevent unfavorable effects upon the columns by its contraction and expansion due to changes of temperature, it has a bearing of steel rollers held together in a frame at the tops of the columns (*fig.* 21). The construction of the vertical supports and their connection with the diagonal braces and tension rods are particularly interesting. Details are shown in horizontal section in Figure 18, in vertical section in Figure 20 and in Figure 17*a*. Of the above-mentioned construction of the support, it may be added that Figure 17, *a* and *b*, gives front and side views and Figure 19 the horizontal section, and that it consists of four angle-irons separated in their length by intermediate pieces bolted to cast-iron shoes above and below, which are common to both. The diagonal ties in cross-section are right-angled, are 4¾ inches wide by ¾ of an inch thick, and are fastened by three screws each, above and below, between corresponding flaps on the shoes.

Arch-rib Roof: Diana Bath.—Figure 22 gives a very interesting example of the second class of iron roofing—namely, that of the arch-rib; it represents the roof of the Diana Bath, at Vienna, built by Etzel. The arch-ribs which form the chief support of the whole roof are constructed like stone or brick arches, except that here the individual parts—made of cast iron—are immovably connected by flanges and screws, thus forming a rigid whole without material horizontal thrust. As the roof is symmetrical on the two sides, with an angle of thirty degrees, and is, moreover, arranged tangentially to the arch-ribs, there arise in each main couple between the arch-rib and the surfaces of the roof and the side walls three similar triangles with equal sides, which are filled up with open cast-iron work. On it are rafter-like pieces, which serve for the reception and securing of the wooden purlins. The span of the whole framework in the clear, between the foot-points of the arches, is 53⅓ feet.

The Drexel Building, in Philadelphia, a typical illustration of recent American practice, worthy of note as a fine example of a great building devoted to business purposes, exhibits certain novelties of construction. The windows are made very wide, the piers are reduced to a minimum, and in the centre of each pier there is placed an iron column on which the floor girders bear, thus leaving the masonry to carry only its own weight. The interior consists entirely of iron construction, the columns being cased with hollow brick as a protection against fire. The necessity of building six stories over the existing banking building of Drexel & Co., and also over a large apartment for the Stock Exchange, the portion of the building above in both cases having no internal supports, presented serious difficulties, but the problem was solved by using heavy iron trusses shaped somewhat like the letter A, rising through four stories of the building (nearly 50 feet), with their bases supported on heavy iron pilasters built up against the inner faces of the walls. These pilasters, which were made in sections of convenient length, bolted together end to end and anchored to the walls, were afterward encased in marble, making a very handsome appearance. Those in the banking building were set up after business-hours, the entire work being carried on without any interference with the daily business routine. The cut (*pl.* 5, *fig.* 2) shows the construction of the trusses which support the floors and roof. The ground-plan of the building is in the form of a huge letter H, each wing being 220 by 56 feet and rising 135 feet above the sidewalk.

Flat or Curved Lattice Girders.—As regards roof-trusses with straight or curved lattice rafters, reference may be made to Plate 4 (*figs.* 23–28), where two examples of the kind will be found. The first (*figs.* 23–27) represents the roof construction of the Otto Circus, in Berlin—a pavilion roof with straight lattice rafters. The second (*fig.* 28) exhibits the roof of the main hall of the St. Pancras Station, in London—a saddle roof with curved lattice girders.

Otto Circus.—The roof of the Otto Circus is polygonal, with a span of 122¾ feet in the clear; it consists essentially of twenty straight wrought-iron lattice girders tapered toward their upper ends, connected above by a cast-iron ring (*fig.* 27), and below by I-shaped wrought-iron intermediate pieces. The ring at the top is required only on account of the lantern set upon it, for without the latter the rafters would come directly together in one point; the lower polygonal pieces, on the other hand, form an essential feature, a sort of anchor by which the horizontal thrust of the construction is entirely eliminated. The lattice girders (shown in detail, *pl.* 4, *fig.* 24) are 30¾ inches deep at the lower and 22 inches at the upper end, and consist, each, of two pair of rolled angle-irons and the flat bars set diagonally between. Two curved tie pieces are set between each two lattice rafters, as shown in Figure 23. Figures 25 to 27 represent the details of the lantern, Figure 25 giving the method of connecting at the heel of the rafters belonging to it, and Figure 26 the connection at the upper end; Figure 27, the union of the tension rods proceeding from the heel of each rafter in a ring common to all. The whole was constructed at the celebrated Borsig Works, in Berlin.

St. Pancras Station.—The roof of the St. Pancras Railway-station, in London (*fig.* 28), which was built under the direction of W. H. Barlow, has a span of 240 feet in the clear, and rises from the walls of the building and directly from the platforms to a height of 124¾ feet in the clear. Each lattice girder has the form of a basket-handle arch composed of four segments of 56.6 feet and 159.5 feet radius respectively, and is 6 feet broad. The angles between the arch, the roof, and the wall are filled in with ornamental open cast-iron work. The principal rafters are placed at intervals of 29 feet, and from one to another are stretched fifteen iron-lattice purlins, each of which carries three intermediate rafters of I-shaped cross-section. In the middle portion the roof is covered with glass to a breadth of 80 feet; the remaining portion is covered with slate.

Frankfort Central Railway-station.—An imposing example of a modern iron-roof structure of the lattice-girder type—perhaps the largest of the kind in the world—is the train-hall of the new Central Railway-station at Frankfort-on-the-Main (*pl.* 5, *fig.* 1). The framework, which has a total span of 551 feet and a length of 610 feet, consists of three semicircular-arched naves, each of which rises in the centre to a height of 93½ feet. The graceful outlines of the interior are especially impressive, and the upper parts of the heavy iron structures, in consequence of their enormous height, look from below like a spider-web. This interesting building is referred to more fully under Railway-stations (p. 212).

Iron Buildings.—Iron has not heretofore been used extensively for the construction of entire buildings, for the reason that stone possesses decided advantages as a material for walls, particularly in producing imposing architectural effects, unless in cases where the iron is made directly to imitate stone. It has also been found by experience that iron in bulk does not furnish a proper substance to incorporate in walls, on account of its great expansibility under the influence of heat; but when used in the shape of thin laminæ, as hoop-iron laid within walls in the bed-joints of the brick or stone, it has no injurious effect, while it is very advantageous in that form as a tie to the structure.

The metal is, however, employed at the present day extensively in edifices not requiring solid walls, such as pavilions, observatories, exhibition-buildings, markets, public-halls, conservatories, etc., which, even when the dimensions are large, should be expressly designed to appear as light as possible, and, while possessing all necessary solidity, should be especially fitted to admit light and air into the interior. To attain this result, glass is extensively introduced, and becomes a very important material in the structure. In shop-fronts iron is also used to a great extent, to dispense with the ponderous masses of stone formerly employed, and for the opportunity of display necessary to such edifices. For the same reason, it is applied to warehouses and public buildings, and is much used in the United States for ornamental façades. In other styles of buildings the use of this metal is exceptional. The principal experiments in this direction have been made in England, where the cheapness of the material has led to its being largely employed in the erection of dwelling-houses for workingmen.

Examples of Iron Buildings: Church at Dünaburg.—As an example of an iron building in the construction of which stone would have been decidedly preferable not only for practical reasons, but also from considerations of beauty, the reader is referred to Figure 29 (*pl.* 4), which represents the church for the fortress at Dünaburg. It was constructed in 1866, of wrought iron, by Von Struve, under whose directions it was put together after having been transported in sections to its place of destination. This little building—intended for one hundred and fifty people only—is said to fulfil its purposes in every respect; its interior is attractive, calling to mind the Græco-Russian style of architecture.

Garden Pavilion and Friedrich-August Tower.—Examples of various iron structures that do not require full side-walls are shown on Plate 6 (*figs.* 1–3). Figure 1 shows an elegant ornamental cast-iron pavilion perfected in a highly characteristic manner; it was opened to the public in 1854, in the Botanical Garden at Munich. It was from the plans of the architect Bergmann, and was cast at the ducal Salm Iron-works. Figure 2 shows the cast-iron Friedrich-August Tower, erected in 1854, on the Löbauer Berg, in Saxony. From an octagonal ground-plan it rises in prismatic form to a height of 93 feet, with a diameter of 147 feet; its walls are entirely of open-work, and on its upper half are three galleries, which run all the way around and are reached by an open-work spiral staircase of one hundred and twenty steps, occupying the whole interior. The various sections are connected by flanges and screws in the usual manner.

Artesian-well Tower.—Figure 3 represents the cast-iron tower-like column of the artesian well at Grenelle, on the Place de Breteuil, in Paris; it is peculiarly graceful and characteristic in form, as well as ingenious and correct in construction. The broad substructure, which is partly of stone, and the tapering of the column, impart to the whole an appearance of great stability. In the centre is the essential part—namely, a hollow cylinder, 26 feet in diameter, which is made of a number of pieces set together, and which serves as a casing to protect the stand- and supply-pipes of the well. Six uprights take the place of outer walls. Between these and the cylinder is a winding staircase which affords access to the three balconies of the column and firmly unites the chief interior and exterior parts. The six uprights on the exterior, moreover, are connected by the stair-railing and held together by the balconies. The open-work steps rest at either end upon suitable supports cast in the same substance as the inner cylinder and the pillars. The column is nearly 140 feet high, and weighs 167 tons. It is connected with the stone substructure by thirty-six bolts of 1½ inches thickness. All the portions of the construction are so calculated and disposed as to resist the most violent winds.

Capitol Dome.—An example of a building in which iron is used in imitation of stone is given in Figure 4 (*pl.* 6). It is the dome of the Capitol at Washington, work of this kind being frequently used in America. The substructure—not given in the Figure—is of stone, as is also a portion of the inner circular base of the dome. The total height from the level of the street to the top of the Figure is 287¾ feet, of which, however, 69 feet are upon the stone substructure. The octagonal base has an extreme diameter of 135 feet, while that of the upper hemispherical exterior part is 104 feet, and that of the rotunda in the clear is 94 feet. Thirty-two wrought-iron girders of lattice-work, tapering toward the top, form the chief supports of the "lantern," as well as of the three domes, placed one over the other; the innermost dome has sunken panels and is left open above, so that the frescos on the vertex of the second dome, which is open at the sides, may be visible. The girders are so held together by a strong iron ring at their base that they cannot occasion any horizontal thrust. The various parts of the construction—for example, cornices, columns, balustrades, etc.—are all of hollow iron, and some are stiffened on the interior by lattice- and web-work. The dome and the wings of this immense building were designed and erected by Thomas U. Walter.

In regard to the above-mentioned iron buildings in hall-form, the reader is referred to Figures 5 and 8 to 11, which include three most interesting examples.

The Market-hall at Lyons, built by Desjardins in 1858, is represented in perspective cross-section in Figure 5. This building, which is beautifully carried out, resembles a basilica—not merely because the whole interior is divided into three aisles by arcades of columns, but also because the height of the middle aisle is greater than that of the sides; the middle aisle also, as is generally seen in the Roman basilicas, is twice as wide as either of the side aisles—that is, 39 feet, as against 19½ feet of the sides; so that the total width in the clear is 78 feet. In its longitudinal measurement we find in each row twenty-one columns, spaced 19½ feet from one another, which corresponds to a total length of 433 feet. The columns themselves are connected, both crosswise and lengthwise, by cast-iron open arches, and the angles left between the arches and the roof are filled in with web-work. A good idea of this arrangement, as well as of the connection of the various parts by flanges and screws, is given in Figure 6; it also shows the characteristic and attractive forms, while Figure 7 shows the details, of the columns. The roof-framing is of wood, except that a saddle of iron rods and glass is set over the middle aisle, to serve as a skylight. In addition to the illumination obtained by this, and the glazed side-walls and ends, light is also admitted through glass in the higher side-walls of the middle aisle, and corresponding ventilation is afforded. There is a cellar under the whole. The weight of the iron-work is three hundred and fifty tons; the total cost was one hundred and ten thousand dollars.

New York Industrial Exhibition Building.—The exterior and interior views of another iron building in hall-form—namely, the industrial-exhibition building erected in New York in 1853—are given in Figures 8 and 9 (*pl.* 6). The ground-plan of this boldly-constructed, light, and elegant building of iron and glass was in the form of a Greek cross, between the arms of which additional one-storied structures of triangular ground-plan were introduced; so that the proper plan of the building took the form of an octagon. The diameter of the entire area, exclusive of the entrances, was 365½ feet. In the centre of the cross a large dome, sixteen-sided in ground-plan, was supported upon slender iron columns; it was 160 feet in diameter by 122½ feet in height to the vertex. The arms of the cross, 149 feet total width, were divided into three aisles of nearly equal width, which were arranged like those of a basilica, or so that the middle aisle was higher than the side aisles. The centre aisle, moreover, was clear to the roof, while the side aisles, with flat roofs, had galleries, and were thus two-storied. Each arm of the cross was flanked by two towers 69½ feet high by 14½ feet in diameter, which contained the staircases leading to the galleries, the principal stairways being near the dome (*fig.* 9).

The lower floor had, in all, one hundred and ninety octagonal columns, of 21 feet height and 7½ inches diameter, with walls from 3¼ to 10 inches in thickness; the upper floor had one hundred and forty-eight columns, of 17½ feet height. These columns were connected by cast- and wrought-iron lattice girders, partly to give stiffness and partly to support the galleries, while semicircular open-work arches served for the support of the roofs over the centre aisle, the angles being filled in with open ornamentation. The cupola of the dome was supported by thirty-two iron arches. The roofs over the aisles, as well as the cupola, were boarded, and covered with tin. The exterior of the whole was painted with oil-color of a bronze shade, the arches and other prominent portions being gilded. The total weight of the cast iron was 1475 tons; of the wrought iron, 295 tons. The total area, including galleries, was 250,000 square feet, and there were 55,000 square feet of glazed surface.

Sydenham Crystal Palace.—Figures 10 to 14 give exterior and interior views, together with some of the details, of the most imposing and largest of iron buildings—namely, the Crystal Palace, built by Joseph Paxton, at Sydenham, in the southern part of London. This immense iron structure was really re-erected from the Hyde Park Exhibition Building of 1851, changes in the dimensions, and also architectural improvements, being made in it when transported to the new site. Among these alterations, the total length was decreased by about 25 feet, and an additional story was placed over the façade next the park, increasing the height by about 40 feet. The building was commenced in the summer of 1852, and was opened in the summer of 1854 for the permanent exhibition of articles of industry and art of all times and of all nations. The main, or centre, aisle is 120 feet wide and 190 feet high; each side-transept, 72 feet wide and 156 feet high; while the total length, without the side-wings, is 1610¼ feet—including them, over 2004 feet—and the total height, 385 feet. There are five galleries placed one over another in the main transept, but elsewhere there are two. Figure 12 (*pl.* 6) gives an interior perspective view of one of the upper galleries; the exterior of all these galleries is seen in Figure 10. All the walls and roofs are glazed. The roofs are supported by large curved lattice girders, as seen in the interior view (*fig.* 11). The details given in Figures 13 and 14 show how the bottom iron columns in the different galleries are connected by flanges and bolts.

The Eiffel Tower.—The most remarkable of all iron structures is the Eiffel Tower (*pl.* 5, *fig.* 3), erected in Paris to serve as a leading feature in the International Exhibition of 1889. As projected, it is extraordinary not only on account of its great height (300 meters, or 984 feet)—which is nearly twice that of the Washington Monument, formerly considered the highest artificial structure in the world—but because it is entirely of iron. It is in the form of an open framework or lattice-work, and, taking into consideration the material employed and the type of the construction, it probably combines the highest attainable strength with the least possible weight. These elements are of prime importance in a work of such unprecedented height; and when the enormous amount of wind-pressure it will be called on to withstand is considered, the suitability of the open framework —which opposes the least possible amount of surface—will be at once apparent. It stands on four great "legs," or lattice columns, each placed at the angle of a square whose sides are 375 feet long. At a point 480 feet above the ground the legs meet at what is called "the middle landing," and from this elevation upward it tapers like any ordinary structure of its kind. Near the summit is a balcony for observation. The tower is terminated by a dome, which, in turn, is surmounted by a smaller dome, around the base of which is placed a small balcony for the use of those who may be venturesome enough to mount to the very top. The four columns forming the base are joined by circular arches, and at this level, its framework resting upon the crown of the arches and upon the columns, is erected a balcony called "the first landing." As the architectural effect depends largely upon leaving unobstructed the central space beneath the arches, the stairways and elevators by which visitors will be able to ascend and descend must be placed in the legs. The total weight of the tower will be 15,400,000 pounds, or 6875 tons.

Iron Stairways.—In regard to the general arrangement of stairways and the proportions of the steps, reference will again be made to what has already been said in the section on Stone Construction (p. 38); it will, therefore, only remain to consider the special arrangements necessitated by the use of iron. It must first of all be observed that for iron stairways wood or stone construction is more or less taken as the model—the former more particularly when wrought iron is employed, the latter exclusively when cast iron is used.

The characteristic feature in cast-iron stairs is that each step is cast in one piece, and is connected with the neighboring steps by screw bolts which are sometimes made as the continuation of the balusters; in this case the screw bolts pass through a ring cast on the end of the step. It need hardly be said that the steps are not solid masses, as is the case when stone is used, but are thin walls; so that the lower or rear sides remain open. The treads and risers have also large perforations. Instead of uniting the steps at their ends by screw bolts in one piece with the balusters, two strips 2 to 2¾ inches wide may be cast along the length of each step, like the oblique rabbets on geometrical stairs, each of which is made to lie upon a corresponding strip of the next step, and is screwed fast to it in several places. This method is mostly employed on the small scale, with steps, say, 3 feet in length for back staircases in winding form. In this case the spindle is cast on each step in the form of a hollow cylinder of equal height with the step—an arrangement corresponding to that so often seen in winding stone stairs. The spindle pieces are rebated to one another above and below, and form a column which has a substantial foundation below and firm connection with the ceiling above.

A stair built in this fashion is shown in Figure 15 (*pl.* 6). It will readily be seen that the construction allows a very light and pleasing treatment, and that contact with the wall is not necessary. The thickness of the metal in a case like the one delineated may be ⅖ of an inch for the treads and the spindle pieces; for the risers, 2½ inches. In straight iron stairs the other form of construction is preferred—namely, the step is made in two pieces, as in wooden stairs, and these pieces are rebated together. They are then screwed, by the aid of three-sided and usually perforated accessory pieces, upon iron cheeks having the form of the I-beam.

V. EXTERIOR WORK OF BUILDING.

1. ROOF COVERINGS.

Roofing Materials.—When treating of the angle of inclination of roofs (p. 48), it was mentioned that this depended chiefly upon the roofing material. The angle varies very much according to the material and the shapes of the individual parts, or is applied differently even when material and shape are the same. The following divisions of material may be made: (1) Tile; (2) Slate; (3) Metal; (4) Glass; (5) Wood, in the form of boards or shingles; (6) Vegetable matter of rough character, such as straw, rushes, etc.; (7) Vegetable matter refined and specially prepared, such as heavy carton paper or linen; (8) Composition—paste, asphaltum, clay, etc. Consideration will be restricted to the first four of the above divisions of roofing material; for the description of the other species, not so generally interesting, the reader is referred to special text-books.

Tile Roofing.—Tiles are slabs of baked clay perforated and shaped in various ways. They are not so much used for roof covering as formerly, as a result of the popular recognition of the superior qualities and the moderate cost of slate. Formerly the business of tile roofing maintained a separate class of mechanics, but the work is now performed by the bricklayer. Tiles for roofing are sometimes colored and glazed, and those of the same style are applied in different ways. The most common are the plain flat tile, the concave gutter tile and roof plate, the ridge tile, and the pantile. To those forms which appear separately belong the different kinds of rebate tile—a tile with turned-up edges.

The Plain Flat Tile is a plate 14 inches in length by 5½ inches in breadth and is $\frac{2}{5}$ of an inch thick. It is provided with shallow grooves and fillets on the upper side, running lengthwise, to facilitate the discharge of the water, and with a lug in the middle of a narrow rim on the reverse side, so that it can be hung up on the roof laths. The other narrow and lower end is generally rounded off into a slight curve. By suspending these tiles to the laths in rows, courses are formed which overlie one another more or less, depending upon the width of the lathing. The greatest overlap or smallest gauge makes the securest work, though it does not present so good an appearance externally as the longer gauge, and it requires, moreover, a greater number of the tiles and laths, thereby adding materially to the weight and cost of the roof.

Single and Double Tiling.—In the single-tile roofing—seen on Plate 7 (*fig.* 1*a*)—this width is about 10 inches. To support the mortar at the joint between each two tiles, small shingles are used. The shingles are about 12 inches long, 2 inches broad, and 1½ inches thick. The second form, or double roofing (*fig.* 1*b*), is decidedly better, the distance between the laths being only 6 inches; so that the first course projects beyond the point on the second below which the third begins. Shingles are not required in this case. Lime, mortar, or occasionally hydraulic mortar, is the connecting medium in the joints and between each two courses where they overlap. In a third form of roofing two courses of tiles are hung, one directly over the other upon each lath, the distance between the laths being 10¾ inches.

Gutter Tiles were used for roofing by the ancient Greeks and Romans, either alone (*fig.* 2*a*) or in combination with the flat tile with raised edges (*fig.* 2*b*). They are conical in shape, the diameter being 9¼ inches at the head and 8½ at the tail, and the length 14¾ inches; while the flat tiles of the same length are 10 inches wide at the head and 12 inches wide at the tail, the edges being raised $\frac{4}{5}$ of an inch. The manner in which the roofing is laid—mortar being employed, as in the use of the plain flat tile—can be clearly seen in the illustration. Gutter tiles are seldom employed extensively in roofing, on account of their great weight, but the ridge and hip lines of tile roofs are always covered in with them. By usage in England, large concave tiles are invariably chosen to cover the hips and ridges, both in plain tiling and in pantiling; they are not generally made to overlap, but are set in mortar and fastened to the timbers of the roof by a special kind of hooks and nails. An ornamental cresting or ridging is also frequently added in a variety of patterns. Tiles of the third order (*pl.* 7, *fig.* 3*a*) have a raised edge on one side and a semicylindrical addition on the other, by which each tile grasps the edge of the one next to it. They are about 13¼ inches long by 8¾ inches broad, slightly overlapping in each row, the suspension being effected by means of the lug.

Pantiles (*fig.* 3*b*) were first used in Flanders, and resemble the foregoing in shape and size, differing only in the cross-section, which is of an undulatory or twisted shape. A small tongue, or lip, is bent from the under side, by which it is hung upon the lath. The tiles are set so as to overlap in a lateral direction, but longitudinally the lap is slight; so that they furnish a much lighter covering than plain tiles. With a more pleasing effect to the eye, there is much less weight, and decidedly much less protection against cold, with greater liability to damage from wind-storms. They are set either dry or in mortar, but pointing upon the inside with lime and hair has been found very advantageous in damp climates. A variety of pantile known as the Bridgewater tile is useful for common purposes. Roofing in the last-mentioned styles is performed upon the principle required for the gutter tile. As the tiles not only touch in each course, but also hook over one another, the joints are rendered tighter.

Rebated Tiles.—The same principle is followed when the rebated tile is used, two examples of which are exhibited in Figures 4 and 5. The tile shown in Figure 4, which was invented by Courtois of Paris, is square in form, 10¾ inches on each side, having two edges projecting upward (*fig.* 4*b*) and two downward (*fig.* 4*c*), these edges being ¾ of an inch in breadth and height. There is a lug, also, for suspension (*fig.* 4*c*). These tiles require a distance between the laths of about 6 inches, as they present square surfaces of only 9¼ inches when set in the roof (*fig.* 4*d*). The thickness of the tile is $\frac{3}{5}$ of an inch. The rebate tiles shown in Figure 5 are also of French origin, and were exhibited, with numerous others, at the Exposition at Paris in 1867. They have rebates on all four sides; so that if the roofing is carefully done it is almost impossible for snow or rain to penetrate even when no mortar is employed.

Among the other styles of this kind of roof-covering, the terro-metallic tile has a projection at the back to fasten upon the laths as a substitute for pegs. Italian tiles have occasionally been used in England for many years; they are slightly curved, fitting easily into one another, have a horizontal inclination across the upper part, to prevent the entrance of rain, and are provided with vertical rolls, either wide or narrow. The chief objection to tiling in damp climates is the rapid absorption of moisture, which, communicated to the laths and rafters beneath the tiles, soon causes the plaster to deteriorate.

In the United States plain tiles are usually ⅝ of an inch in thickness, 10½ inches long, and 6¼ inches wide, weighing from two to two and one-half pounds each. They are generally hung upon the lath by two oaken pins inserted into perforations made in the tile; they have grooves and fillets on the edges, so that there is little necessity for overlapping, as the grooves conduct off the water. Pantiles are used 14½ inches by 10½ inches in size. Semicylindrical tiles are named "crown," "ridge," "hip," and "valley" tiles, the name indicating their purpose. Siding tiles are sometimes used instead of weatherboarding, and are made ornamental, being often decorated upon the surface with crenated edges.

Slate Roofing.—Slate in thin sheets has recently become very popular as a roofing material. The varieties found in England are excellent in quality and varied in appearance. That of a blue-gray tint is esteemed as the best, and answers to a sharp stroke with a ring like that from well-baked pottery. Blue-green and green slates are good, and are admired for their coloring, those of a light gray tint being generally stony, while those of the darker shades, though cutting freely, decay rapidly by absorption of moisture. The poorer and more absorbent qualities are smooth and greasy to the touch, the best being hard and rough. Two methods—distinguished as the German and the English—are practised in roofing with this material.

Diagonal Slating.—In the German method (*pl.* 7, *fig.* 6)—known as "simple diagonal roofing"—the slates are nailed in diagonal rows, supported on boarding in such a manner that each individual row, as well as each slate of which it is composed, is made to overlap. The upper and the lower courses—that is, the eave-course and the ridge-course—run horizontally. The nails by which the slates are secured are driven only through the parts that are hidden. The slates are cut straight—at least, on two sides—though they are not of equal breadth throughout.

Double Slating.—The English method—known as "double roofing"—corresponds to the double roofing with plain tiles. The slates, generally 24 by 15 inches, are made to meet one another flush, and the first course overlaps the second past the point where the third begins. The courses being here set horizontally, the wooden boarding may be replaced by laths. Figure 7 shows the form of roofing with wooden laths, and Figure 8 that with iron laths. The pair of nails required for each slate in the case of wooden laths are to be driven as deep as possible, but so that they shall be covered by the next slate. Sometimes, as the Figure shows, an additional nail is driven at the upper edge; so that only half the head overlaps.

Slate Fastenings.—The double roofing on iron laths shown in Figure 8*a* is accomplished in an ingenious manner by means of a specially-formed hook. An enlarged view of the latter is given in Figure 8*b*. The hook hangs upon the lath above, and grasps the slate below in the middle of the lower edge; so that the hook lies in the joint between two slates of the row next below. To prevent the suspended slate from being lifted by the wind, a small cross plate is fastened to each hook, and is made to lie under the two slates that meet at the hook. Each hook is 4¾ inches long by $\frac{2}{5}$ of an inch broad, and should be made of copper or galvanized iron. In nailing slates, any straining or bending must be carefully avoided. By a method used in France, slates are fixed in place by a wire clip which holds the bottom of each slate; for the same purpose there has also been introduced a lead clip which, it is claimed, diminishes the quantity of slate required.

Bedding for Slates.—In covering a roof with projecting eaves, a broad board is placed over the end of the rafters; but when the eaves tail into the rafters, the gutter-board should be of sufficient width to receive the eaves-course. In light slating it is considered best to cover the roof entirely with rough boarding, but for heavy slates fillets, laths, or battens are used, and applied to suit the length of the slates, at the convenience of workmen. A feather-edged board—styled a "tilting fillet"—is laid against gable- or party-walls, to turn the water. In case of a hipped roof, every course is completed up to the angle by shaping the slates to fit the slope, and these are covered by an overlap of sheet lead screwed or nailed to the hip rafter. It is usual to employ slate ridging with a roll, or with a groove fitted to receive the ornamental crestings which are so popular. Elastic cement is also preferred as a bedding for the top course on the ridge and for a space around the hips, valleys, and gutters. Tarred-felt roofing paper is also placed between the roof boards and the slates.

Sizes and Names of Slates.—In the English market the popular sizes for slates have received the following singular names: "ladies," measuring 15 by 8 inches; "countesses," 20 by 10 inches; "duchesses," 24 by 12 inches; and "queens," 36 by 24 inches—increasing in value as they ascend in rank, with the singular inconsistency that a thick queen is known as a "Welsh rag" and a smaller lady is called a "double." The thickness of the slates varies from $\frac{3}{16}$ to $\frac{5}{16}$ of an inch. Recent authorities in the United States give the pitch of a slated roof at about 1 in height to 4 in length, the laps being about 3 inches, or a little more. Slate has usually been classed among the incombustible materials, and as such is especially adapted to use in building; but it cannot be depended upon as a resistant against fire, as it cracks on the application of heat.

Metallic Roofing.—The defence of roofs from fire and moisture by the application of complete coverings of thin sheets of metal has long been practised and is very general, the choice of the material depending mainly upon cost and the peculiarities and variations of climate. As a rule, the sheets should be laid in such a manner as to require the minimum amount of soldering, and to permit the unavoidable expansion and contraction of the metal to take place without injury to the roof. An under course of boards usually supports the metal, but by certain methods this support is rendered unnecessary. To insure the security of the work strict attention must be paid to the points where the sheets are joined, and a clear distinction must be preserved between the horizontal joints running in the long direction of the roof and those running from the ridge to the gutter. In the horizontal joinings, folds are usually so arranged that the ends of the sheets are bent either upon or over one another, and are afterward hammered flat. By this means the water, as it runs down, is kept from penetrating beneath the sheets, while the necessary freedom of action in the metal is insured.

Instead of these foldings, the sheets are sometimes merely overlapped for about 4 inches. The joints running down toward the gutters are secured in different ways; the most usual methods are seen in Figures 9 to 12 (*pl.* 7). Figure 9 exhibits what is known as the "standing seam," in which the junction of the ends of the sheets is accomplished in a manner similar to that in the horizontal joint, except that it is not hammered flat. The attachment to the roof boarding is secured by a tongue of iron nailed on one side to the under course and soldered on the other to the sheets where they meet. Figure 10, which shows the rolled joint to which the tongue is also applied, requires no further explanation. In the lath joint, shown in Figure 11, the ends of the sheet are bent up over a wooden fillet and nailed fast on one side over the ends, a special metal cap being placed and also nailed fast to the fillet, the heads of the nails being soldered. Figure 12 exhibits the covered fold, where the sheets, after being rolled together and held by the tongues, are covered by a special cap of metal which grasps the rolls.

Metallic Tiles.—Besides the foregoing, metallic shingles of various decorative designs, imitating the appearance of the finely-finished terra-cotta tiles, are in the United States much in vogue on steep roofs. In respect of fire- and storm-proof qualities, these have all the advantages possessed by terra-cotta tiles; they are in no wise inferior to the latter in attractive appearance, and in respect of durability and lightness are distinctly superior. Figure 13 (*pl.* 2) shows one of the forms of metallic roofing tiles in common use. These tiles have a thickened edge, which adds greatly to their appearance. When laid, they slightly overlap at the edges; so that the nail holes are covered. The usual dimensions of these tiles are 5 × 5 or 6 × 6 inches.

Corrugated-iron Roofing.—In the modes of roofing already mentioned, a support of boarding is absolutely necessary; Figure 13 (*pl.* 7) exhibits the method applied when corrugated sheets are used. Metal thus formed by rolling has much greater stiffness than ordinary metal, and can lie free over much larger spans. As the corrugations must run in the same direction as the roof gutter, it will be seen that the plan exhibited in the illustration is suited only for purlin construction. The overlapping of the sheets, about 4¾ inches, and the tongues for securing them, are shown on the Plate. Corrugated iron laid upon roofs in sheets should overlap about 2½ inches along the sides and 4 inches along the ends, and about 6 inches is usually allowed for extension over the eaves. This substance offers an excellent and permanent protection.

A serious objection to simple iron roofing—known as "black iron"—is the very rapid condensation of the atmospheric moisture, which falls from the metal like drops of rain and is likely to injure the ceilings beneath; and this danger is not entirely removed by painting, although it can be prevented by plastering. This material is, however, very enduring when kept thoroughly defended by paint composed of some mineral oxide, the sheets being overlapped and folded at the edges and placed upon sheeting boards. Galvanized iron, which is much used, and which is very useful for roofing, is manufactured by applying a thin coating of zinc to both sides of the sheet of iron by immersing the latter in a bath of molten zinc.

Tin-plate Roofing.—The tin plate, also used extensively for roofs, is produced by covering iron sheets (in the same manner) with a coating of tin or of an alloy of tin and lead. The sheets of tin—or, rather, of iron faced with tin—are joined together in the shop, end to end, by being bent over, hammered flat, and then soldered. When each sheet is of the required length to reach from the eaves to the peak of the roof, it is, for convenience, turned into a roll and carried to the roof, where it is spread upon the sheeting boards and joined to the next length along the edges by bending, and for further security is fastened by cleats about 18 inches apart. Terne, or sheet iron covered with a mixture of tin and lead instead of with tin, is frequently used for the same purpose, but is not so durable, although less expensive. The best plates of both tin and terne are made from charcoal-iron, which is tough and does not suffer from bending; iron made with coke is inferior in this respect. Tinned and leaded sheets of Bessemer and other steel are also used.

Zinc and Copper Roofing.—Zinc, like tin, furnishes an excellent resistant to the moisture and changes of the atmosphere. Zinc in sheets, laid like slates, is much employed in various parts of Europe, and proves very durable, as a thin film of white oxide collects upon it by exposure to the weather and increases its resistant power. Copper as roofing material is applied in sheets 5 feet in length by 2½ feet in breadth, and is laid on boards, to which it is held by copper cleats.

Glass Roofing.—Glass is used for roofing only when light is to be admitted through the entire surface or by a skylight. The glass sheets, either of ordinary or of cast glass, are best laid upon bars of I-shape cross-section, and are, as usual, glazed with putty. In skylights arrangement should be made to carry off by small inside gutters any leakage or condensed moisture gathering on the inside. In large roofs it is not desirable to trust to putty, and there are now introduced many different systems of glazing which, while aiming at freedom from leakage, permit the glass to expand and contract at the edges. For skylights from ¼ to ½ inch in thickness a thick ground-glass is made which has the effect of preventing the full glare of the sun, and of diffusing the light over a much greater space below. Where skylights are glazed with clear or double-thick glass, it is used in lengths of from 16 to 30 inches by a width of from 9 to 15 inches. A lap of at least 1½ inches is recommended for the securing of all joints. Fluted glass (sheet-glass rolled so as to form flutes or corrugations on both sides) is best suited for this purpose, as it secures privacy without obscuring light, while it is stronger than ground-glass. The

Crystal Palace in London affords an example on a large scale of complete, and at the same time original, roofing in fluted glass, a specimen being shown in Figure 14 (*pl.* 7).

Sheet Iron for Exterior Finish and Decoration.—The employment of galvanized sheet iron for the exterior finish and ornamentation of buildings has become very general in the United States, and by its use the most elaborate decorative effects are obtained. It is chiefly employed for cornices and roof crestings, for which it is well adapted as a fireproof covering. It is also applied to the fronts of buildings, to columns, etc., in imitation of wood, stone, or iron. Figures 8 and 12 (*pl.* 2) show respectively the mode of attaching a sheet-iron cornice by braces extending through the masonry, and the appearance of a finished cornice. Figure 10 shows a roof cresting, and Figure 7 shows a capital of a column.

2. ROOF GUTTERS AND WASTE-PIPES.

Roof Gutters and conductors, or waste-pipes, were formerly constructed of lead, copper, or tin, but recently tinned or galvanized iron or zinc has been almost exclusively employed. Gutters may be arranged in various ways, but care should always be observed that they have a fall of about one to the hundred, to facilitate the draining of the water.

Hanging Gutter.—The simplest but least elegant style is the hanging semicylindrical gutter, shown in Figure 15 (*pl.* 7), which is suspended by means of iron straps directly beneath the eaves in front of the upper parts of the cornice. The appearance of the cornice is thereby injured, especially as the gutter must necessarily be set in a slanting direction. Figure 16*a* exhibits the highest, and Figure 16*b* the lowest, point of the gutter, while Figure 15 shows the fastenings or supports, which are about 2 feet apart. The metal in this form of gutter is rolled up on the outer edge and connected with the iron by small metal straps soldered on. A much better form of gutter is so placed over the lower courses of the roofing, and likewise secured by straps, that the next courses overlap it; in this style the gutter lies with its rear surface against the roof-planking, but in other respects the arrangement is similar to that of the hanging gutter.

The Box-gutter (*fig.* 17) is the form to be preferred. It is concealed from view by an upright fillet in front, which forms a kind of coping over the cornice and prevents it from being seen from the outside. This gutter is usually made roughly in wood and then lined with zinc. It is clearly shown in the illustration, which also exhibits the opening into the conductor or waste-pipe, an accessory piece being added, and also a strainer, to prevent any obstructive matter from entering the waste-pipe. The parallel or box-gutter is necessary next to parapets, where a curb roof is formed, and is useful in valleys of small roofs where there is sufficient depth. When the walls are thick, it is usual to place this form of gutter below the timbers of the roof, whereby they are kept dry and damage from overflow is avoided. This can also be done by using a projecting cornice, the gutter being formed on it in place of a real blocking course. When the edges of the metal sheeting are turned up against the side of the chimney shaft or the back of a blocking course, instead of being turned into the joints of brickwork or into a raglet in stonework, the edges should be left and a flushing added. This flushing is a narrow strip of tin, zinc, or copper secured along one side in the joints or raglet, the other end being bent over the upturned edge of the gutter metal, which it should overlap about 4 inches. By this means one edge of each piece of metal is left free for expansion and contraction. The apron, or overhanging piece, is secured by being burned in or run into the groove in the top of the blocking course, the metal being finally caulked or punched into the groove.

Roof gutters are now frequently made of cast-iron pipes, generally of either half-round or ogee section, and in lengths of 6 feet, the half-round pipes being from 3 inches to 6 inches in bore, and the ogee from 3½ to 6 inches. Lead, formerly used extensively for roof gutters, has been superseded by other metals, as it is liable to perforation by vermin, nails, or corrosion.

Rain-pipes or conductors (*fig.* 17) descend vertically, and are composed usually of cylindrical sections of tinned or galvanized iron of suitable diameter for their intended service, joined together, and secured at distances of about 6 feet apart by collars or soldered to flat straps fastened to the wall. They are fitted with large case heads above, to receive the water from the roof gutter, and with shoes below, to eject it in the required direction. Rain-pipes of corrugated sheet metal have lately come into very general use in the United States. They have the advantage of being free from liability to bursting from the freezing of water within them, the corrugated form permitting of an increase of sectional area (*pl.* 2, *fig.* 11).

3. PLASTER-WORK ON EXTERIOR OF WALLS.

In plastering on stone and brick, only one coat of brown mortar is used. In this hair is not considered essential, but a little more sand than usual is added to the mortar. The wall should be well dampened before the application is made, and the mortar itself is made more plastic, works more easily, and attaches more quickly to the wall when thinned with water. When too little sand is used, the plaster is apt to crack in setting and drying, and crumbles easily; almost the same effect results from too much sand; so that a knowledge of the sufficient quantity can be obtained only by experience. Upon external walls the second coat should consist wholly or partially of cement, equal parts of lime and cement making an excellent composition. If the wall be exposed to the effects of water and frost, the introduction of sifted sawdust mixed with the water will prevent the scaling off of the plaster. When the work is done in dry and windy weather, the wall should be frequently sprinkled with water, to prevent too great rapidity in drying, and in damp places cement should be used instead of fat lime. The work in cement must be executed rapidly, and only so much mortar mixed as can be used before it begins to set.

Rough-cast.—This cheap and excellent covering for outer walls, when they are protected by projecting eaves, is applied in the following manner: The surface is indented or roughed and then well brushed, to cleanse it from loose fragments. It is then covered with the rough-cast, which is mortar thinned by water to which pure lime is added to make it of the consistence of cream. By another process the roughened wall is sprinkled with water and coated with lime and hair; when this is set, a second coat is laid smoothly, and upon this is dashed an almost fluid mixture of fine gravel and strong lime well mixed. This last is immediately washed with an ochreous color, and dries into a compact mass. When plaster is directly applied to brick, concrete, stone, or other surfaces than lathing, the work of putting on the first coat of coarse material is termed "rendering" instead of laying or plastering; and therefore, although the material applied and method of application are the same as on lathing, one-coat work is termed "render;" two-coat work, "render-set."

Stucco.—The common quality of stucco is composed of one part of lime to three or four parts of clean-washed sand. When employed with coarse sand for finishings in imitation of stone, it is called "rough stucco," the surface, to give it an appearance of the grain of sandstone, being raised by rubbing with a hand float or small flat board with a handle at the back. In the composition of stucco, there are four bushels of fat lime to one bushel of hydraulic cement, with sand as six parts to one. A setting or finishing coat in common plastering is called "fine-stuff," and consists of a pure lime slaked with a small quantity of water, being afterward thinned to the consistence of cream. It is left to settle; the surface water is drained off, and then the mass is allowed to evaporate until thick enough for use, when it is usually styled "putty."

Cements.—Many kinds of cements are used to obtain a hard, non-porous surface capable of resisting weather. Portland cement is almost universally employed for external walls, having superseded Roman cement, which, although valuable as quick-setting, is not considered reliable. A superior quality of the Roman—known as the Medina—cement is of a lighter brown color, sets rapidly, and has borne exposure to water. Mastic, well suited to outside work which is to be painted immediately, is expensive, and metallic cements, having a metallic lustre intended to dispense with coloring or painting, have been used to some extent.

Sgraffito is a revival of an old Italian method of decoration. The process may be briefly described as follows: A coat of colored plaster of the tint of the proposed design is applied to the wall, and upon this is placed another coat of the tint intended for the grounding color. A mould in zinc of the outline of the intended design is then fixed on the surface; its outer edge is traced, and the upper coat of color is then cut away with a sharp tool down to the face of the lower coat. Even three coats are sometimes applied, and a considerable variety of coloring is thus produced. A good specimen of this work is displayed on the outer walls of the National Training School of Music, South Kensington, London.

4. LIGHTNING CONDUCTORS.

Lightning conductors—first proposed about the middle of the last century by the philosopher Benjamin Franklin as a protection of life and of buildings against the destructive effects of lightning—perform, when properly erected, a double office. In the first place, by silently drawing off the accumulated electricity of the clouds, and thus permitting it quietly to pass into the earth, explosive discharges of the electric force are prevented. In the second place, when the accumulated electricity in the atmosphere has acquired a tension sufficient to overcome the resistance of the stratum of air intervening between the earth and the charged cloud, the conductors afford a better path than any adjacent bodies by which the explosive discharge may find its way to the earth. To express this second function of the properly-arranged lightning conductor more accurately, it may be said that it presents a path of least resistance along which the electricity, in finding its way to the earth, will naturally pass in preference to any other.

Materials.—From the foregoing statements, it is obvious that the lightning rod must be composed of a material of a high electric conductivity, and that it should be of sufficient size to enable it to carry off harmlessly into the earth the largest discharge that may be attracted by it. Of all known materials, the metals are by far the best conductors of electricity, and are, therefore, universally employed in the construction of lightning rods. The metals, however, differ greatly in respect of conductivity; but, for the purpose of this sketch, only copper and iron need receive consideration. Of these, copper, when quite pure, has about six times the conductive power of iron, but, taking the metals as they are found in common use, the former may be said to have about four times the conductivity of the latter. It must be borne in mind, therefore, that an iron rod, to be as effective as one of copper that has been found to be sufficient, must have at least four times the sectional area of the latter.

Dimensions and Shape.—Regarding the proper dimensions of lightning conductors there are some differences of opinion. The French Academy, with reference to iron rods, recommended that such should be made of a square bar from ½ inch to 1 inch in cross-section; if of copper, they could be made much thinner. The shape to be given the rod is a subject of small importance, provided the amount of metal in it is sufficient. Many rods are manufactured in the form of thin-walled tubes or twisted ribbons of light weight, under the impression that by giving the metal a greater surface its conductivity is thereby increased correspondingly. This is an erroneous view, as it has been fully demonstrated that electricity, whether of the quality known as lightning or as current electricity, travels through the mass of a conductor, and not over its surface; and the principal reason why the venders of lightning rods recommend such light-weight ribbons or tubes is because they can be sold cheaply. In all cases, a solid bar of square or rectangular section (if of iron) or a twisted cable of wires (if of copper) should be selected in preference to the various ribbon patterns.

Erection of Rods.—With regard to the placing of rods upon a building, it is essential to observe that they should be so arranged as to afford the most efficient protection; this is of more importance than the practice of carrying them up to a considerable elevation above the roof. Escaping vapor, smoke, or moisture from chimneys and other portions of a building may form ascending currents, which, under suitable conditions, will afford a better path for the lightning than an elevated rod upon another portion of the building; and from this cause there may arise many apparently inexplicable accidents from lightning in the case of buildings having conductors. It is generally assumed that a lightning rod properly connected with the earth will protect an area about equal to that of a circle of which the rod is the radius. This will generally be a safe estimate, but it is well to bear in mind that to prevent any injury to the building and its occupants the rod must present a better earth connection than any neighboring body. Should there exist within the building large metallic masses, water- or sewer-pipes, isolated from the rod, but in better earth connection, the lightning may descend the rod to the point nearest the last-named bodies and leave the rod at this point to seek the earth by the better avenue, destroying, in so doing, whatever may be in its path. On this account it is to be recommended that the rod should always be connected by good metallic connections with all large bodies of metal within the building, such as water- or sewer-pipes.

The arrangement usually adopted consists in erecting upon each of several chimneys a terminal spike or point, and connecting these points with a single main lightning conductor or leading them directly and independently, by separate rods, to the earth. The first plan is the preferable one. In the case of a building of considerable extent, two or more rods may be advisable, but ordinarily one main conductor, properly grounded, will be found to afford ample protection, provided connection has been made by metallic rods extending over every portion of the roof. A metallic roof, when connected properly with the earth through the medium of rain leaders, will afford immunity from damage by lightning as completely as the most elaborate system of rodding. When the roof is surmounted by ornamental crestings of metal, it is obvious that these, when suitably connected with the ground by a metal conductor of ample area, will serve every purpose.

Rod Termination.—The rod is usually terminated either by a point (*pl.* 7, *figs.* 18, 23, 25) or by a sphere, which it is customary to gild or platinize, though the last-named refinement is quite unnecessary. The commission of the French Academy which lately examined and reported on the subject recommended as a very satisfactory form of termination "a cylinder of copper $\frac{8}{10}$ of an inch in diameter and 8 or 10 inches long, the summit being tapered off into the form of a cone 1¼ or 1½ inches high." For practical purposes, it makes, really, little or no difference whether the rod be terminated by a point or by a blunt or spherical extremity, although the former style is most generally adopted, as affording better conditions for the silent discharge of an electrified cloud. The continuity of the conductor should not be broken at any point, and the safest plan, in the case of rods of solid metal, is to join the successive sections to one another by screw sleeves of the same metal, so applied that the ends of the united sections shall abut directly against one another.

Insulators and Fastenings.—The use of insulators of glass or porcelain in making the attachment of the rod to the building, which is often practised, is an unnecessary precaution; for it is absurd to assume that a lightning flash which possesses sufficient intensity to break through hundreds of feet of air will be prevented by the interposition of a few bits of glass an inch or two in thickness from leaving the rod and seeking a better path, should one exist. The fastening of the rod to the building, therefore, should preferably be made as direct and simple as possible. Professor Phin, a reliable authority on this subject, recommends that "if the rod be flat it may be pierced with small holes and tacked directly to the building; but a better way for either round, square, or flat rods is to employ properly-shaped staples of stout wire. These staples may be driven into the studding of wooden houses or into the joints of brick walls, and when properly painted will not present an unsightly appearance." Where something better than staples is desired, he proposes a strap of metal of the same kind as that of which the rod is made, and "pierced with two holes, whereby it may be attached to any structure by means of a couple of screws. . . . . The advantages of this device are that it does not weaken the rod, is not unsightly, permits the rod to slide on the building as it expands and contracts by heat and cold, and permits it easily to be applied or removed without injury to the building." Several illustrations exhibiting the details of construction will be seen on Plate 7 (*figs.* 18–25), all of which are so sufficiently explanatory as to make a special description unnecessary.

Earth Connection.—The manner in which a lightning conductor will perform its intended service will depend absolutely upon the perfection of its connection with the earth. The good features above enumerated may all be present; yet if the ground termination be imperfectly made, the rod will be worse than useless. Defective ground connection, as attentive observers have frequently demonstrated, is the cause of the great majority of accidents that happen to buildings presumably protected by lightning rods and supposed to be safe. There are two conditions relating to the ground connection of a lightning conductor which must be regarded as essential. The end of the conductor must be made to terminate in ground that is permanently wet, and it should be made to expose to this wet soil as large a surface as practicable. In the erection of a conductor, the importance of these conditions should not be underestimated, for upon them will depend the ability of the rod to conduct away the electrical discharge and dissipate it harmlessly in the earth.

The practice of placing the lower end of the rod in water is much less effective than to bury in the earth a considerable length of the rod, leading it away from the building, and surrounding it with coke. Phin, in his excellent treatise on lightning rods, approves this plan. His advice is as follows: "If a trench 10 feet long be sunk to the depth of permanent moisture and filled to a depth of 12 inches with coke, it will be ready to receive the end of the rod, and will furnish a path for all the electricity that will ever tend to escape from the clouds to the earth."

5. PAINTING AND GLAZING.

Painting.—The labor of the painter consists chiefly in applying an impervious covering or coating, of which drying oil is the base, to buildings as preventive of decay and for purposes of ornament. In outside work the chief aim should be protection from the alternations of cold and heat, wet and drouth, and, incidentally, from sulphurous gases present in the atmosphere, especially in manufacturing cities. When durability in timber is of primary consideration, some authorities suppose that the rough surface left by the saw offers the best resistant against weather; and when the wood has not been properly seasoned, the application of paint and varnish has the effect of causing dry rot by confining the interior moisture within the timber.

Materials.—The principal material used in house-painting is either white lead or oxide of zinc, ground in unboiled linseed oil to the consistency of paste. As a preparation for immediate use, it is further thinned by the addition of more linseed oil. Driers are added, to hasten the process of hardening, as each coat should dry thoroughly before the next is applied. Litharge, japan varnish, sugar of lead, and sulphate of zinc are used as driers. Turpentine as a thinner should be used sparingly in outside work, as it is apt to impair the firmness of the paint, and to cause it to blister under the heat of the sun. Various compounds have recently been introduced to meet objections to the ordinary lead and zinc paints, based on their poisonous nature, chemical effect upon metals, sensitiveness to various gases and vapors, and offensive smell. The evaporation of turpentine proves very injurious to the health of many persons, and paints have been invented in which lead and zinc may be mixed with methylated spirit containing shellac, with a small quantity of linseed and castor oil. The spirit, evaporating, allows the shellac to set as a substitute for the film of varnish deposited in common paint by the oil and turpentine.

For exterior use, anti-corrosive paints made of equal parts of white lead and ground glass have been extensively manufactured. As waterproof defences, silicates have been introduced successfully. What have been styled "indestructible" paints have been composed of oxides of zinc and lead, with petroleum-spirit holding resinous matter in solution. Paints of oxide of iron combine intimately with iron, forming a durable protection against dampness. Tinned iron exposed to weather is well protected by Spanish-brown paint, and lime with sulphate of zinc makes an excellent wash for exposed walls of brick and stone. Fireproof paints and washes are effectual when combined with silicates. Sulphate of lime, with coal-tar, diluted with naphtha, is also durable against weather. Pitch and wood-tar are used extensively as preventives to dampness. Other applications have for their object the protection of stonework against deterioration from atmospheric causes. They are chemical washes, of various composition, which by their presence prevent the destruction of the surface of the stone. The Houses of Parliament have been subjected to treatment of this nature, but with indifferent success.

Painter's Work.—The first coat, or priming, for outer woodwork is composed of lead mixed with raw linseed oil, with a drier of litharge ground in turpentine. This composition sinks promptly into the wood and hardens upon the surface, preparing the way for any after-treatment and economizing the paints applied later. Some authorities advise that turpentine should not be used in this priming. After this coat is dry, all holes are carefully stopped with putty, so as to present a smooth surface for the more ornamental coats to follow. The putty used for this purpose is composed of whiting kneaded with linseed oil, white lead being added to increase the hardness. Painter's work is frequently estimated by the square yard, it being supposed that a pound of paint covers four superficial yards in the priming, or first coat, and six yards in each of the subsequent coats, and that a pound of putty is used in every twenty yards. A day's work on the outside of a building has been estimated at 100 yards of the priming and 80 yards for each of the outer coats.

Glazing.—The business of the glazier is confined merely to fixing or inserting pieces of glass into sashes of wood or iron or into leadwork. The sash bars, either of wood or of iron, are rebated on the outside, and the glass is stopped into them by a bed of putty. A coat of paint is always placed upon the sash bars or upon the rebates, to prepare the sash for the reception of the putty, which would not otherwise become firmly attached. When this paint or priming is sufficiently dry, the pane is fitted in with such nicety that a point can hardly pass between the sash and the pane, the object being to permit the glass to be incased completely in the putty, which must be very narrow in extent. When the size of the pane is thus assured, a slight tracing or bed of the putty is carried around the sash bars and the light fitted into it, being rubbed down carefully with the finger, so as to force the putty into a complete framing for the glass, which is bedded back against it and secured in the rebates by putty in front, sloping from the inner to the outer edge. The putty on both sides should then be covered with a coat of paint, to prevent shrinkage. When large and heavy panes are used, they are further secured by small brads of iron or copper, hidden from view by the front putty. The edges of the large plates in doors are for greater safety often bedded in wash-leather. In very large lights, as further security against the constant contraction and expansion of the material, the putty is made constantly pliable by a mixture of tallow or oil, so that it may change with the movements in the glass.

Lead Glazing.—In lead glazing—now generally confined to churches—the glass is placed in the grooved edges of narrow leaden bars, which are opened up to receive it and then closed firmly upon it. These leaden bars are then soldered together into squares, diamonds, and other forms, or are bent to the shapes of the different pieces of glass used in the pattern. In the latter case it is styled fretwork. The fanciful styles of modern architecture have introduced much ornamental glazing, with glass of many styles of colorings.

Varieties of Window Glass.—Polished French window glass is prepared in lights or panes from an inch square to a width of 8 feet and a length of 14 feet. The difficulty in manufacturing the larger panes causes the price to rise in a rapid ratio. Plate glass is esteemed very highly, as it does not yield to the diamond and cannot be noiselessly removed; it is sometimes rolled, ribbed, or plated, and is also made in diamond patterns. Ornamental glass for windows is made ground or obscure, with a transparent figure finished by polishing away the portions of the rough surface. Common window glass is $\frac{1}{16}$ of an inch, and the double-thick glass nearly $\frac{1}{8}$ of an inch, in thickness. The latter is much stronger than the thinner form.

VI. INTERIOR WORK OF BUILDINGS.

Flooring.—Reference has heretofore been made to this subject in connection with the discussion of proper supports of floors, the weight they should be able to bear, and the methods adopted in Paris for diminishing fire-risks and preventing sound from readily passing from one story to another (p. 46).

Strength of Floors.—A primary consideration is strength. An indication of the requirements deemed essential is furnished by the statement that the New York building law provides that in all buildings every floor shall have sufficient strength to bear safely upon every superficial foot of its surface seventy-five pounds, and, if the buildings are used as places likely to be visited by large numbers of persons, one hundred and twenty pounds. In reference to the supports of floors, the building laws of the cities of New York and Boston require that in all buildings more than 30 feet in width, except car-stables, churches, theatres, schoolhouses, and other public buildings, the space between any two of the bearing walls shall not be over 25 feet unless girders are substituted for the partition-walls.

Variation in Strength of Floors.—There is a great variation in the actual requirements for strength in the floors of the buildings of different classes, the extreme range being, according to one of the estimates, from forty pounds per square foot in dwellings to four hundred pounds per square foot in factories. In cases where unusually heavy weights will probably be applied, safety should be assured by a proper apportioning of the strength of floor beams and the floor to all possible demands. Neglect of this duty, the natural effects of decay, and the weakening influences of alterations in various buildings are the primary causes of a considerable number of so-called "accidents" in which persons are injured or killed. Text-books contain rules by which the strength of floor beams can be calculated and due allowance made for the factor of safety. The average weight of the floors in dwellings is estimated at from seventeen to twenty-two pounds per square foot of floor, including the weight of the plastering on the under side. For ordinary spans the weight is frequently about twenty pounds, and for long spans about twenty-two pounds, per square foot. In public buildings the weight per square foot seldom exceeds twenty-five pounds. Factory or warehouse floors required to sustain heavy loads sometimes weigh from forty to fifty pounds per square foot. All floors in first-class buildings should possess not only sufficient strength to resist fracture, but also sufficient stiffness to resist bending under any load to an extent that would cause the ceiling underneath to crack or to present a bad appearance to the eye. To insure appropriate safeguards, the thickness and weight of the material used in American floors are frequently proportioned to the superficial load the floor is intended to bear.

Classes of Flooring.—In English practice, three kinds of flooring are extensively used; they are classed as "single flooring," "double flooring," and "frame flooring." The first, or single flooring, is supported solely by a row or tier of joists extending from one wall or partition to another, and it receives the flooring boards on the upper surface or edges of the joists and the ceiling on their lower surface. This form of flooring does not provide for the prevention of the transmission of sound from one story to another, and the joists used are sometimes too thin fully to serve all desirable purposes. Double flooring consists of three distinct series of joists, called "binding," "bridging," and "ceiling" joists. In this system the binders are the real supports of the floor; they run from wall to wall and carry the bridging joists above them. Frame flooring is a construction of girders with binding, bridging, and ceiling joists.

Improved Flooring.—Notable improvements in the construction of the floors of factories, warehouses, stores, and large buildings in business centres intended for the use of numerous tenants as offices, etc., have been extensively introduced during a comparatively recent period. They embrace better provisions against the dangers of fire and better methods for preventing the transmission of sounds and vibrations than were formerly common. In some forms of fireproof floors the principal materials used are brick and hollow terra-cotta tiles, supported, usually, by iron beams (*pl.* 2, *fig.* 3). In others considerable quantities of mortar are intermingled with the foundations of wooden floors.

Partitions are defined as the interior walls of a house. Their number, the materials of which they are composed, and the mode of their construction frequently bear an important relation to the extent to which safeguards against fires are provided, and also to the degree of strength and thickness requisite in the party walls by which buildings in cities are separated. In the construction of fireproof buildings, it is considered essential that they should have no wood partitions unless they are protected by fireproof material. It is said, however, that partitions built of two-inch tongued and grooved planks placed together on end and plastered on both sides, either on wire or on dovetailed iron laths, have offered effective resistance to fire.

Brick and Timber Partitions.—Partitions of large structures are generally formed of brickwork, while in smaller buildings or in the upper parts of dwellings wooden material is frequently used; but it is often filled in between the uprights by brickwork. In England, partitions of timber are called "quartering partitions," and they are generally framed. Thin partitions of wood are called "frame partitions." The method pursued in Paris is to frame and brace with strong seasoned timber. After the framed structure is complete, strong oak batten-laths from 2 to 3 inches wide are nailed up to the quarterings horizontally, 4, 6, or 8 inches apart, in accordance with the character of the work, throughout the height of the partition; and the spaces between the quarterings and behind the laths are loosely built up with rough stone rubble, which is kept from falling out by the laths until a strong mortar—composed mainly of plaster of Paris—laid on and pressed through from both sides at the same time, meets and incorporates so thoroughly that it fills up all the interstices and serves to strengthen the wooden material used, instead of deriving from it support.

The English Brick-nogged Partition, formed of a similar combination of materials, depends for its strength chiefly upon the timber used, as the plastering work performed is nicely spread upon the surface of brick and wood; and these differences in effects represent important distinctions in methods of constructing partitions consisting of wood, stone or brick, and plaster or mortar.

Plaster-work.—Plastering on the interior of buildings, on lath, brick, or stone, usually consists of three coats of mortar. The first—called the "rough-" or "scratch-coat"—is generally formed of one part quicklime to four parts sand, with ox- or horse-hair mixed in to make the mass cohere. This coat, which is put on with the trowel, is about half an inch thick, and is pressed firmly in, so that it may enter well between and behind the laths. For rough walls, as in cellars, the scratch-coat may be sufficient. To furnish a better adhering surface for the second coat, the surface of the first coat, when it has dried slightly, is scratched or scarred with a pointed stick in lines crossing one another diagonally from 2 to 4 inches apart. The second coat is of the same hair-mortar—known as "coarse-stuff"—being from ¼ to ⅜ of an inch in thickness, and is also in turn roughed before the application of the next coat, this roughing being frequently done with a hickory broom. The third and finer coat, intended as a finish, is generally but ⅛ of an inch in thickness, and is frequently of stucco, which is made of one part lime to two parts fine sand. For a hard finish, one part plaster of Paris to two parts lime is used, without sand.

Hand-floating.—To produce a fine finish upon inner walls, the surface is hand-floated, or polished. This is done with a wooden trowel, called a "hand-float," and a water brush to dampen the wall as required. For very fine work the hand-float is made of cork. This careful smoothing upon each of the outer coats improves the strength and firmness of the wall, producing an excellent and permanent covering. Sea-sand cannot be used in making plaster for this purpose, as it cannot be washed free from salt, which collects dampness in the wall; the hair from salted hides should also be avoided, on account of its causing dampness in mortar.

Screeding.—To make a perfect surface in fine walls and correct any warping or irregularities, the plasterer depends upon a process called "screeding." To accomplish this, when the first rough, or scratch, coat of mortar is partially dry additional horizontal strips of the same mortar, about 8 inches wide and from 2 to 4 feet apart, are laid over the entire wall, so as to project from the first coat to the intended surface of the second coat. These are while soft carefully regulated by a plumb-line, and the second coat can then be readily brought to a perfectly flat surface corresponding to these strips or screeds.

Scagliola is a plaster imitating marbles. It is composed of plaster of Paris and size, with coloring-matters stirred into the mass. This, with different kinds of the finer cements, is much used for wall panels and pilasters, and for imitation marble pillars. Large interior as well as exterior surfaces are often quite successfully finished in imitation of granite. To accomplish this, after drying the second coat of plaster a coat of lime tinted with umber is applied, and allowed to dry. It is then finished with a wash of lime, and a mineral black is sprinkled on with a brush, to imitate the spots in the granite.

When interior surfaces are intended to be painted, a much-used preparation known as "trowelled stucco" is carefully made from fine lime and clear sand. There is also a variety of cements which may, by constant trowelling and wetting, be worked into a very hard surface capable of a polish like marble, and it can be decorated by the painter.

Lathing.—When plaster ceilings are to be fixed upon the under side of floors or plaster coverings affixed to wooden partitions, the preliminary operation is lathing, or covering the surface to be worked upon with wooden strips or laths. In the United States, laths are generally of split white or yellow pine from 3 to 4 feet long, 1½ inches wide, and ¼ of an inch thick. In England firwood from the Baltic is usually employed. Sawn laths have a uniform thickness and require less labor in finishing the wall, but are more liable to break. Laths of metal have also been introduced to some extent. A distance of ¼ of an inch between laths allows for shrinkage; when placed closer the clinches are apt to be weak, and when more distant the laths sag upon ceilings and drop off on the sides by their own weight. To obtain a perfectly true surface upon which to attach the laths, the under sides of joists in ceilings or the battens or quartering in walls are provided with a straight edge, and are corrected either by adzing off projections or by bringing up inequalities by nailing on strips of wood to the requisite height—an operation variously called "furring" or "firring." The laths are laid side by side, and the ends should abut and never overlap, being secured by one nail at each end and one at each intermediate point of support.

Woven-wire or Sheet-metal Lathing.—Of late, various metallic substitutes for wooden lathing have come into use, and have the advantages of affording better adherence of the plaster and of materially lessening the liability of the spread of fire. Of these substitutes, woven wire is one of the most efficient and best known. Perforated sheet iron, either plain or galvanized, has also come into prominence for the purpose. One of the best of these substitutes is shown in Figures 5, 6 (*pl.* 2).

Mouldings and Cornices.—Decorations immediately under the ceilings of rooms require special attention. For the cornice moulding, two plaster screeds are run with the trowel—one on the ceiling and the other on the side walls—at such a distance from the angles that the moulds can slide over them. A thin wooden screed is also temporarily fastened upon the wall as a guide upon which the mould can slide in a straight line. To make the work secure, the laths of the wall are left bare to the width of the cornice, so that the plaster may clinch safely between them. What is styled "gauged stuff," or plasterer's putty and plaster of Paris mixed carefully for immediate use and in small quantity, is then prepared and thrown rapidly into the angle with the trowel to an amount fitted to fill the mould, which is promptly run over it, cutting away all superfluous material. The mould is then scraped clean and again run over the moulding. The scrapings can be hastily added to any defective member of the design, and the mould again applied. When the form is found to be perfect, a gloss is given by the brush, and the work proceeds to another segment of the cornice. When mouldings are not continuous, but enriched, they can usually be run as if continuous, with the enrichments added afterward, the latter being castings of plaster of Paris secured into place with cement or screws. Large cornices, panels, and mouldings are sometimes made upon canvas or wirework strained over wooden frames, which can be readily placed in position, the entire work being washed over with the gauged stuff. Mouldings and skirtings in exposed situations are made of Portland cement, which can, when necessary, be faced with one of the white cements.

Cast centre-pieces, rosettes, brackets, and similar ornaments, are made of thin plaster poured into a mould through an orifice. The moulds are usually in sections, and are made of plaster hardened with glue or shellac. Such ornaments are attached to their places by fresh plaster, and when required are secured with screws, to support the weight. Large central mouldings, either circular or elliptical, are also made by the same method as the cornice, the mould being run from a central point by an arm or trammel upon a screed of the required shape and dimensions. An interesting departure in this field of decoration has been made by the adoption of sheet metal of elaborately ornamental designs for ceilings, more particularly for centre-pieces. These pieces can readily be attached and removed, and, having no disposition to crack, are superior in durability to the above-named plaster-work of the same kind.

Decorative Work.—The ornamentation of interiors is continually becoming more complex and luxurious, and its extension into dwellings of the cheaper grades has developed extraordinarily during recent years. The introduction of artificial stone and cements susceptible of fine coloring can only be mentioned, with the endless variety in the application of tinted slates and glass. Tiles in intaglio and enamel produce highly artistic effects in form and color, with moulded and tinted brick, and the innumerable applications of terra-cotta. By the use of these adjuncts, the flooring and walls for vestibules and halls, hearths, and fireplaces are made very elegant at comparatively small cost. The vast improvements in paper-hangings also assist in the decoration, as do the ingenious adornments added to the necessary work of the plumber. Carpentry in the hard woods, merely oiled or varnished, has largely taken the place of the former imitations in graining; which art has, however, also been greatly developed for inferior purposes. As a matter of progress, the substitution of the real and substantial for the imitative and unsubstantial marks an advance in public taste; while at the same time the immense and varied application of science, which beautifies and supplies cheaper substitutes, is also rapidly tending to the extension of architectural beauty in every direction.

Painting.—Although the primary object of painting is the preservation of surfaces, yet in work upon the interior of edifices decoration specially applicable to domestic and other uses becomes a subject of importance. According to the present rulings of fashion, the house-painter practises two distinct systems of decoration. In one he merely covers all the wood surfaces with a transparent coat which allows the original graining and tinting of the material to appear, this preservative covering being linseed oil or varnish; by the other method he covers all the surfaces under his care with an opaque substance which hides the original material entirely. In most cases, this was formerly the ordinary white paint, composed of linseed oil and turpentine containing white lead or oxide of zinc, to which has recently been added an almost infinite variety of pigments for the purpose of decorative coloring. It is considered that a successful treatment with paint requires four or five distinct coats, each of which should become perfectly dry before the application of the next. By the changes of public taste, a dead or dull finish is sometimes popular, and at another time a glossy one is required. The dull effect is produced by using turpentine solely to dilute the last coat of paint; the glossy effect results from the natural surface of the paint when mixed with oil or equal parts of oil and turpentine.

Graining—the technical term for the imitation of the color and grain of superior woods upon those of inferior quality—has been recently brought to a great degree of perfection, and even during the present prevalence of the taste for carpentry in hard woods a house is seldom completely finished without the introduction of graining. A simple following of nature—which should be the aim of the painter—is all that is here needed; inferior work is apt to be more pronounced in color and forms and too glaring in general effect. Distemper, or water color, is very successful for graining in interior decoration when the colors are thin, so that the varnish penetrates into the ground-color, making it as durable as oil color, with an especially soft and realistic result.

Distemper and Fresco.—White distemper is produced by mixing whiting and size, and the colors are made merely by adding the required pigment to the whiting in the requisite proportions before mixing it with the size. Superior work in the adornment of walls and ceilings is done by laying on the distemper cold, and as thick as jelly. Silicate distempers make an excellent waterproof surface for hospitals, and for such walls as for sanitary reasons should be frequently cleaned with water. The higher form of artistic decoration known as "fresco" is produced by painting with water color upon fresh-laid plaster; the coloring-matter, drying with the plaster, becomes intimately united with it, and is quite permanent in dry situations.

It is found prudent to guard against dampness in plastered walls by covering them with a tint in distemper for the first two years. If the surface is then in good condition, a coat of oil can be added for a permanent decoration; or, as the wall has then become perfectly firm, the distemper can be washed off, and the more durable oil-paint can be affixed after the surface has been dried. In oil-coloring, when very clear tints are required, the nearly colorless poppy-oil which is expressed from the seeds of the poppy-flower is used instead of linseed oil. In more careless practice, the first coats under colored paint have been laid in white and the tinting added only in the last coating. By a better method, the prevailing tint is introduced into the priming coat and all subsequent ones; fractures upon the surface are thus prevented from being so unsightly by immediately exhibiting the imitative character of the work, and the whole is made more durable.

Marbling, or the imitation of real marble by painting upon stucco and the finer cements, furnishes a beautiful decoration, and is a very useful adjunct where either the expense or the weight of the original substance is to be avoided; and it has been carried to such a high degree of perfection that its spurious character can be detected only by touch.

Haste seems the greatest obstacle to success in all these departments of ornamentation, well-seasoned wood and perfectly dried and settled walls being the prime necessity for durable effect.

Gilding.—In gilding, gold-leaf is the most successful application, though many of the gold paints are useful in some situations. In using the leaf, a coat of japan gold-size is first applied and allowed to become nearly dry, when the metal is laid on and pressed into place with a tuft of cottonwool. When applied to bare wood, the gold-leaf is finally coated with pale copal varnish. When gilded in oil, the wood, after being smoothed, is coated with a gold-size composed of yellow ochre and linseed oil, and the leaf applied. All metallic sheetings are thus fixed, and silver-leaf, when finished with transparent yellow varnish, has the appearance of gold. Castings, mouldings, and carvings are treated in the same manner.

Paper-hanging—which is simply the pasting of paper upon walls—is an art intimately connected with personal and domestic comfort. The convenience of removal and renewal puts it under easy control as a ready, economic, and immediate alteration upon an interior, while the immense variety of styles furnishes the means of making a thorough change in the entire tone and aspect of the house. The removal of wall-paper may obviate the danger of contagion, and its renewal substitute cleanliness as well as an absolutely new scheme of color and form, producing almost unlimited variations of effect. Taste is here absolutely dominant, as no rules can be given suited to the size, purpose, or proportions of the several apartments, which are further modified by exposure to light and air, with the multitude of other accidents which give each room, especially in a dwelling-house, a particular individuality. The progress in this art has kept step with the rapid development of domestic architecture, and styles are offered as adaptations of almost every school of art and every national taste, with an unlimited opportunity for amateur or sentimental expression on the part of the individual customer. New walls are frequently allowed to remain uncovered until well seasoned or until they become soiled before the paper is affixed. To secure neatness as well as permanence to the new covering, former paper should be thoroughly removed by scraping and washing. As a preparation, the walls should receive a coating of a size made of a weak solution of glue and water. Upon this the paper is placed, being first thoroughly covered on its under surface with a paste made of wheaten flour moistened with cold water and then diluted to a convenient consistency by stirring in boiling water. A small quantity of alum is added, and the paste is used when cold.

Wall-paper.—The qualities and grades of papering may be said to be innumerable, varying as they do from an article which can be placed upon the wall at the cost of two and a half cents for a running yard of 18 inches' width to the favorite Lincrusta Walton, which may cost ten dollars for the same amount. The lower orders of machine-printed papers are placed on the market at twelve cents for a piece of eight yards' length and width of 18 inches, the hangers charging, usually, twelve cents for applying it; but there are cheaper papers placed on the wall for an entire cost of twenty cents for the piece of eight yards. Papers printed by hand bear exceptional prices, according to the freaks of fashion, and can be furnished by the yard according to order. The old satin papers with brilliant white ground and burnished gold figures, and the gorgeous velvet papers, have been superseded by quiet effects, or by the sombre richness of the varied bronzes. For the present, it may be said that the prevailing fashion demands plain side walls with decorated ceilings, the ceilings being also papered of one uniform tint, with fresco added upon the top of the paper with fine effect. The new felt papers are almost as thick and soft as the fabric from which they are named, and in plain tint give excellent relief to the elegantly ornamented friezes.

Various styles of the higher grades of paper resemble mouldings tinted with metallic lustres. Cork paper is highly embossed, and what is called "lining paper" imitates a gilt or bronzed relief, and is very durable. These expensive grades, with the Lincrusta Walton, are used, in turn, as backgrounds upon which the decorative artist places further ornaments in high relief in bronzes and gold suited to the special architectural features of the buildings to be adorned. Some of the most usual present styles, beginning with the cheapest, are known as "white blank," "flats," "bronze," "embossed bronze," "silk paper," and "silk finish." The flock or velvet paper once used so largely is now more sparingly introduced for its richness and depth of tint. Japanese leather papers, cartridge, and many others, are in use with waterproof qualities, and with others already varnished.

Plumbing is defined as the art of casting and working in lead and using it in building, especially in arranging pipes for conducting water. Iron has, however, almost entirely superseded the use of lead. Plumbing has been of the highest utility. Primarily it lessened human labor by bringing water within the reach of private dwellings, and latterly it has not only introduced supplies of water by the easiest methods, but has also undertaken to remove all the waste water, together with filth and sewage. The complications arising from this double duty, as well as the further work of systematizing the general water transport of all the organic waste of large cities to places of safe deposit, make the subject assume gigantic proportions. When the requirements of manufacturing industries and the supply of the modern conveniences of steam and gas are also added, the province of this art enlarges to a vast extent. Plumbing has recently come prominently before the attention of the public from the growing conviction that the cause of many diseases can be distinctly traced to defects in drainage, especially to the escape of sewer-gas, and a multitude of inventions have been advocated in the aid of sanitary reform.

Sanitary Regulations.—The necessity for such general regulations as may harmonize individual exertion for the benefit of the community at large has received extensive recognition, and the character of these requirements may be conveniently summed up as expressed in an ordinance for the regulation of plumbing enacted by the city government of Boston, Massachusetts, in March, 1883. The provisions may be condensed to the following main points: Every building shall be separately and independently connected with the public sewer, when such sewer is provided, and, if such sewer be not provided, with a brick-and-cement cesspool of a capacity approved by the inspector. Drains and soil-pipes for the carriage of water and sewage shall be of iron when within the building, and for not less than 5 feet outside the foundation walls thereof. They shall be sound and of uniform thickness of not less than $\frac{1}{8}$ of an inch for a diameter of 4 inches or less, or $\frac{5}{32}$ of an inch for a diameter of 5 or 6 inches, with a proportional increase of thickness for a greater diameter. They shall be securely ironed to walls, laid in trenches of uniform grade, or suspended to floor timbers by strong iron hangers, as the inspector may direct. They shall be supplied with a suitable trap, placed, with an accessible clean-out, either outside or inside the foundation wall of the building. They shall have a proper fall toward the drain or sewer. Soil-pipes shall be carried out through the roof, open and undiminished in size, to such height as may be directed by the inspector; but no soil-pipe shall be carried to a height less than 2 feet above the roof. Changes in direction shall be made with curved pipes, and connections with horizontal pipes shall be made with Y-branches. Rain-water leaders connected with soil- or drain-pipes shall be suitably trapped. Sewer, soil-pipe, and waste-pipe ventilators shall not be constructed of brick, sheet-metal, or earthenware, and chimney-flues shall not be used as such ventilators.

Iron pipes, before placing, shall be tested by the water or kerosene test, and then coated inside and outside with coal-tar pitch applied hot with paint or some equivalent substance. Joints shall be run with molten lead, thoroughly calked, and made tight. Connections of lead pipes with iron pipes shall be with brass ferrules properly soldered and calked to the iron. Every sink, basin, bath-tub, water-closet, slop-hopper, and each set of trays, and every fixture having a waste-pipe, shall be furnished with a trap, placed as near as practicable to the fixture that it serves. Traps shall be protected from siphonage or air-pressure by special air-pipes of a size not less than the waste-pipe; but air-pipes for water-closet traps shall be of not less than 2-inch bore for 30 feet or less, and of not less than 3-inch bore for more than 30 feet. Drip- or overflow-pipes from safes, under water-closets and other fixtures, or from tanks or cisterns, shall run to some place in open light, and in no case be connected directly with the drain, waste-pipe, or soil-pipe. Waste-pipes from refrigerators and other receptacles for provisions shall not be connected with drains, etc., unless provided with traps suitably ventilated. Other particulars are clearly specified, with such minute directions as fully show the consideration given to the subject and its importance as a means of promoting the health of the community.

In 1885 the State of Pennsylvania passed an act authorizing the Boards of Health in cities of the first class to regulate house drainage, the registration of master-plumbers, and the construction of cesspools. By this enactment, the drainage of all buildings erected before 1886 was to be inspected, and when condemned altered to the new regulations, while the plans of all new erections were to be presented for approval to the Board of Health with specifications of the size and kind of pipe, traps, closets, and fixtures. The sanitary regulations of the act were very complete, and by a later amendment it is required in Philadelphia that all soil-, waste-, and anti-siphoning pipes, and traps, inside new buildings and in new work or alterations upon old buildings, shall be tested to an atmospheric pressure of three pounds to the square inch. So important has such general regulation been considered that the Society of Arts in London made a formal proposal that the Metropolitan Board of Works and the County Board of each county shall be empowered by the legislature to make provision for the inspection and sanitary classification of dwellings upon application being made by the owners thereof, and to grant certificates of healthfulness.

Desirable Ends.—The general result of the varied consideration of the subject may be stated thus: That all pipes should have such fall and be so flushed as to render any accumulation of waste impossible; that leakage both of liquid and of air must be prevented; that the piping should be in full view and easily accessible for repairs and cleaning; that it should be concentrated as much as possible in one portion of the building; that simplicity of arrangement is conducive to safety; and that all piping should run as directly as practicable.

Modern Sanitation.—One of the modern suggestions is substantially as follows: That a broad recess built in the masonry of a party-wall in the line of the bath- and toilet-rooms could connect the necessary plumbing with the smoke-flue of the furnace, the heat from which would promote circulation in a ventilation-pipe. The recess, enclosed in masonry, with brick platforms on the line of the floors, made tight around the pipes with cement, would protect the woodwork from overheating, while all parts of the plumbing could be left readily accessible. The soil-pipe should be supported upon the foundation wall or upon a pier, and the junction with the drain-pipe be made with an easy bend, to prevent the accumulation of obstructive matter and to lessen the back-pressure of air upon the traps. The main drain should run in full view upon the foundation wall or in a trench of concrete, with a fall of ½ an inch to the foot when practicable. It should be trapped just inside the cellar wall when possible, or otherwise in a manhole outside. A water-conductor run into this trap would insure its flushing. A fresh-air inlet just inside this main trap provides a complete circulation through the soil- and drain-pipes. To assist the free flow, all angles and bends in piping should be as smooth and gradual as possible. Circular apertures assist the discharge, offering less obstructive surface in proportion to the area; and small orifices, from friction, discharge less under the same pressure than those larger and of the same shape. The discharge of a cylindrical horizontal tube can be increased by extending it to a length four times the diameter of its orifice. Wrought-iron pipes suited for water service range in diameter from ½ an inch to 16 inches.

The Pressure on Plumbing varies through an extensive range. In cities where dependence is placed upon the natural head at a distributing reservoir, the pressure is often very light, while in cases where pumping machinery is used and a head maintained in stand-pipes, or where the water is delivered into the main pipes directly from pumps, the pressure may rise to above one hundred pounds to the square inch.

Gas-fitting.—Arrangements for the introduction of gas into buildings located in cities and large towns were formerly almost universal, and they are still very general, but during recent years they have to some extent been supplemented by, and intermingled with, devices pertaining to electric lighting.

Gas-pipe.—The ordinary methods of introducing gas are ranked among the simplest of mechanical operations, but they should nevertheless be conducted with due regard for such requirements as are essential to safety and efficiency. Failure to secure an appropriate relation between the size and strength of the pipes used and the amount of gas consumed in an entire building and its various subdivisions may lead to disappointing or dangerous results. It is also important that all soldering of joints should be performed in a thorough manner, and that a judicious selection and adjustment should be made of burners, chandeliers, and other fixtures.

Service-pipes.—The ordinary arrangement of the gas supply of the house consists, first, of an inlet-pipe of iron, bringing the gas from the street main to the meter, which is usually placed in a portion of the cellar as near the street as possible. From the meter an iron pipe passes up to the level of the first floor requiring a supply of gas. Here branch-pipes are led off to the various rooms, while the principal pipe is continued upward to the other stories as far as desired, and connections made with it which lead to all desired points on each story. In English practice, cast-iron pipes are used for diameters above 2 inches, and wrought-iron for those of smaller bore. In Paris the gas-pipes must be visible for their whole length, except when passing through a floor or a partition, when they must be let through a larger pipe having both ends open. In the United States, strict regulations were established in some of the American cities at the time gas was first introduced, but to a considerable extent their enforcement has been abandoned.

Gas Fixtures.—The burners to which gas-pipes lead are broadly classed in two divisions, one consisting of brackets or side lights, and the other of pendants which hang from a ceiling. In choosing a location for a bracket, care should be taken that it may not reach any movable article of an inflammable nature, such as curtains, cupboard or closet doors, etc. In the case of a pendant, the principal considerations relate to the strength of the connections by which it is supported, and to an avoidance of interference with the free movement of persons beneath it. The pipe to supply a bracket should be carried as directly as possible between the point in a wall from which it projects and the main supply, which may be in the ceiling above or in the floor beneath or in the wall of an adjoining room or passage. Aside from the adjustment of the pipe which makes such connections, special pains should be taken to insure reliable joints and to perfect the soldering and other necessary operations. In hanging a pendant, the supply-pipe is brought between the joists of the ceiling of the room to the desired point and appropriate connections are made, care being taken to secure proper provision for the strength of all the appliances used..

Modern Improvements in Gas Fixtures.—A great many designs of burners, chandeliers, pendants, brackets, and glasses for enclosing gaslights have been introduced from time to time. Aside from the changes in ornamental effects which they represent, there are modifications which, it is claimed, possess economic significance. It is said that the old practice of making of metal the point of burners in contact with the flame, instead of some non-conducting substance, such as steatite, was radically defective, and that it necessarily led to a great waste of gas. Improvements in the construction of burners have also been found advantageous. It is found that the size of the burner should be proportionate to the quantity of gas to be consumed, and that the gas should issue at a very low velocity. Respecting the use of glass globes, experiment has shown that perfectly plain and clean glass absorbs at least one-tenth of the light that passes through it, ground-glass absorbs one-third, and ordinary opal glass abstracts at least one-half, and generally more. Such globes should have an opening at the bottom at least 4 inches wide, through which the air can pass without disturbing the flame.

Electric Appliances.—The rapid advances made during recent years in the application of electricity to practical purposes include a number of improvements which have a direct or indirect connection with building operations. They relate to the ringing of door-bells or call-bells located in various portions of dwellings (*pl.* 8, *fig.* 17), annunciators in hotels, etc.; to lighting, heating, the signalling of fires, the detection of burglars; to furnishing of power, methods of summoning police or messengers, telephonic communication, and various other purposes.

Electric Lighting.—Systems of lighting interiors by electricity have been extensively introduced, especially in the United States, and appropriate arrangements have been devised for conducting wires to the desired points in all parts of buildings. In connection with this subject, dangers have been developed against which ample precautions are provided; but neglect of these safeguards and careless workmanship have in some instances led to deplorable accidents. The vital matter is the proper installation of electric-lighting circuits.

As deaths also have occurred from accidental contact with poorly-insulated electrical wires, all who participate in the introduction into buildings or the arrangement or repair of wires which are to be charged with electric currents should obtain and act in accordance with information that will insure safety.

Electric Burglar-alarms.—For the protection of buildings from robbery, so-called burglar alarms, consisting of an alarm- or signal-bell set in operation by the making or breaking of an electric circuit by simple mechanism in connection with the doors and windows, etc., are in very general use. Another form of this class of appliances is a combined floor-mat and burglar-alarm which is sufficiently ingenious to warrant a special description. It comprises an electric alarm-bell, a mat-carrying circuit, and closing and breaking devices, so that when the mat is subjected to pressure an alarm is sounded. The mat consists of narrow strips of wood connected to a fabric backing, and on the strip side of the mat is a series of springs which support the mat, there being two separate wires and the springs being securely connected to each wire. When the mat is stepped upon, the springs are compressed, contacts are made, and a current is sent through the connecting wires (which are embedded or grooved in the wood) to the bell electro-magnet, so as to sound an alarm. The bell has a switch or lever on the frame, by means of which, when moved, the vibrating adjustments are displaced, and the current ceases to flow through the armature spring or circuit breaker; it then passes directly through the magnet, and upon the movement of this switch or side lever greatly lengthens the stroke of the armature, which is essential when a single stroke only is desired.

Prevention of Water Overflow.—One of the modern inventions provides a method for the prevention of the overflow of water in buildings by automatic electric devices, by which the loss and damage caused by the bursting of pipes in winter and by carelessness in leaving water-cocks open may be avoided.

Miscellaneous Electrical Devices.—The list of electrical devices and of methods of accomplishing given ends by electrical agencies is too extensive for elaborate discussion here. Enthusiasts assert that a very wide range of the labors performed in dwellings can be facilitated by electrical devices, and they look forward to discoveries in the near future which, by cheapening the cost of existing methods, will lead to the extensive introduction of numerous inventions hitherto used only experimentally or on a limited scale.

Door and Window Fittings.—Under this title are included the appliances—made chiefly of iron, but sometimes of other metals—that form parts of the movable means by which rooms are opened or closed, and particularly the metallic adjuncts of doors and windows that facilitate motion, add strength, and otherwise increase efficiency.

Hinges.—When a door or a window moves on an axis, hinges are used to effect this rotary movement. These vary greatly in size, shape, and other particulars, to correspond with the diversified requirements of the woodwork to which they are attached, but in every case they consist of two interlacing parts—namely, the supporting and the hanging portions, the former being attached to the casing of the aperture, and the latter to the door or window. Different styles are illustrated on Plate 7 (*figs.* 26–29). Figure 9 (*pl.* 8) exhibits a self-fastening shutter hinge, by which window shutters are securely fastened when open.

The Strap Hinge (*pl.* 7, *fig.* 26) is frequently used on ledged and framed doors. It aids in strengthening them, and in mediæval times such hinges often had an ornamentation of a twisted or interlacing description which covered the greater part of the leaf to which it was attached. In the illustration the supporting part, or dog—upon the pin of which the hinge, screwed to the door-leaf, hangs—is provided with a plate, also attached by screws to the woodwork with which it is connected. The loop of the hinge, resting upon the pin, has a small pin of its own screwed in, so that the one pin works upon the other. Each leaf of the door generally has two or three hinges.

The Cross-tailed Hinge (*fig.* 27) is used chiefly on heavy external doors. As the three sections in the Figure show, the horizontal part lies between the fillets of a plate with eight screws and is itself screwed to the leaf by a strong screw bolt. The arrangement of the supporting dog and of the pin connected with it is similar to that of the strap hinge described.

above. Additional particulars are shown by the vertical section of the illustration.

The Butt Hinge (*pl.* 7, *fig.* 28) is extensively used on doors and windows. It differs from those previously described chiefly in the fact that its fastening parts are sunk into the leaf as well as into the jamb casing. Three screws in each part furnish additional security. Only the knuckles receiving the pin on both parts of the hinge remain visible on the outside, the flaps being sunk into the wood. Small doors have two such hinges, and larger ones have three. In American practice, the species of hinges designated "butts"—often made of bronze or of brass—are extensively used as attachments for facilitating the movements of doors or window shutters. Leading varieties are styled "loose-joint butts," "loose-pin butts" (*pl.* 8, *fig.* 11), and "fast-joint butts."

The Charnier Band or Pivot Hinge (*pl.* 7, *fig.* 29) has two flaps, each fastened with three screws. These flaps are not mortised, but are let into the face of the fold flush with it. The knuckles of the flaps do not lie over, but are let into, one another and connected by a pin. The illustration embraces two vertical sections in addition to the external view, and is intended to show how a movement of one hundred and eighty degrees may be made and how the two parts connected by the hinge may be brought closely together. In elevated structures these hinges are used chiefly for folding window shutters.

Rollers.—If a door or a gate is moved by sliding, and not by turning on an axis, rollers are used, to diminish friction. Figure 31 illustrates both running rollers and sliding rollers, the first of these terms being applied when the rollers are at the top, as in sliding doors in rooms, and the second when they are at the bottom, as in doors of magazines. The lower part of Figure 31 furnishes side and sectional views of the running roller, which moves on a horizontal pin screwed between iron plates and is guided by an edge rail. The sliding roller seen in the upper part of the Figure is smaller and lighter than the running roller. It is also guided by a rail, and lies between a prolongation of two angle-irons which are fastened to the door.

The Sliding Bolt (*fig.* 30) is an appliance used specially on two-leaved doors. It might probably be most appropriately classed among fastenings, as it serves to secure that one of two leaves which is not generally opened, being applied to both the upper and the lower end of the leaf. Various details are shown by the illustration. When the doors are very high, the top bolt is made long enough for the handle to be easily reached. When the bolt is heavy, a flat spring is put between it and the plate by which it is supported, so as to prevent its falling by its own weight when driven up. On doors of rooms the bolts are generally countersunk. Figure 10 (*pl.* 8) shows a secret-spring latch for office doors, etc., and Figures 13 to 15 the ordinary thumb latch.

Window-fastening Appliances.—Doors, particularly those opening on balconies, often have the same fastenings as windows. Window fastenings can be moved on the inner side only, and such movements are made without the use of a key. There are three leading varieties—namely, the turn-buckle, the espagnolett, and the bascule.

Turn-buckles may be either half buckles or whole buckles. Figure 32 (*pl.* 7) illustrates a half buckle—used chiefly on one-sash windows—in plan and vertical section. One end of the turn-buckle is secured by a pin, so that there may be revolving movements on a plate screwed to the framing, while the other end lies on a plate screwed down on one side only, which when the buckle is not on it stands off slightly, but is pressed down by the buckle. Instead of this plate, a wire sunk in the wood is frequently used. The whole turn-buckle (*fig.* 33) closes two sashes simultaneously, and is fastened so as conveniently to accomplish that object. Each pair of sashes in the window has two of these turn-buckles and two knobs; and when the mullion is movable, the division carrying the latter will also require sliding bolts or two half turn-buckles. Figure 7 (*pl.* 8) is a form of catch for fastening inside window blinds or shutters, and Figure 8 is a fastening for sliding sashes.

The French Lever is a modification of the turn-buckle and forms a portion of the espagnolett fastening (*pl.* 7, *fig.* 34). It is used on windows with a movable centre mullion, and affords this advantage—namely, that the shutting or opening of both sashes is simultaneously effected above, below, and at some intermediate point, or in three places, while with the turn-buckle fastening and the movable mullion four manipulations are required to close both sashes, consisting of the movement of the whole turn-buckles and of two half turn-buckles. Two additional movements of the knobs are requisite to open the sashes to which turn-buckles are attached. The triple fastening is accomplished by means of a vertical rod, from ⅜ to ½ inch thick, secured so as to be able to revolve between the two sashes, thus coming upon the movable mullion (*fig.* 34*c*) by collar hoops or rings (*fig.* 34*d*). This rod has solid hooks at the ends, and on some point in its length a lever which can be rotated up and down (*fig.* 34*c*). The middle fastening is effected by laying this lever over into a catch on the other sash which does not carry the movable mullion, while simultaneously the hooks on the ends of the rod engage in lock hooks, one of which is placed on the transom and the other on the window sill, or, as seen in Figure 34*a*, in corresponding hooks screwed on at these points. In opening, the lever is first thrown up and off and the vertical rod is rotated by the lever, used as a handle, the hooked ends of the rod being disengaged by this movement.

The Bascule Fastening (*fig.* 35) is also used on windows having a movable mullion, and it too effects a fastening in three places. It is a superior form of bolt used in connection with a stop. The rods lie either upon or inside of the movable mullion, and can slip vertically up and down into striking plates or lock hooks screwed on at such points as would be selected if the espagnolett were used. The rod may be in one or more parts. In the latter case, the two parts move in opposite directions; and all the various arrangements found in bascules are intended to effect this movement in different directions simultaneously with the lifting or falling of the stop. One of the best arrangements is seen in Figure 35*b* (*pl.* 7). The stop is moved up and down by the handle (*fig.* 35*a*, *c*), while at the same time the small cog-wheel inside is made to turn, and by engaging in the cogged ends of the two bolt-rods it forces them up or down. If the bolt rod is in one piece, it must be hook-shaped at the end, and so curved that when the window is opened the hook is drawn out of the staple, while in closing one end engages as usual and the other curved end shoots into the staple from the opposite side.

Locks are appliances by which doors, lids of desks, trunks, etc., are temporarily fastened in such a manner that only the possessor of a key of peculiar form can loosen or unlock the fastening by the slipping of a bolt; and this key is also necessary to repeat the operation of closing or locking.

The French Lock (*fig.* 37), which is one of the simplest forms of lock now extensively used, is well suited for the doors of dwelling-houses. The bolt stands in a quadrangular box or rim. Its head—or double head (as in the Figure)—after passing through the cramp of the rim, enters the corresponding opening or openings of the catch fastened on the door-jamb or in folding doors on the leaf not generally moved. The end positions of the bolt are fixed by a spring lever, the tumbler, which must always be lifted by the wards of the key before the bolt can slide. The effective turning of the key results, first, in lifting the tumbler by the bolt, and, second, in moving the bolt, both in locking and in unlocking. The return of the tumbler to its resting-place is effected by a spring.

To increase the difficulty of imitations of the key, wards (*fig.* 38) composed of sheet metal are set inside the rim, which prevent the key from being turned if its wards have not openings shaped to correspond exactly with the form of the profile of the guard. Changing the form of the guard furnishes a simple method of varying the locks and keys of a house or of a story in a flat or hotel, the arrangement being otherwise similar. At the right of the top of Figure 37 is the key of a French lock with complicated wards; under this is a blank key, by which, if it is covered with wax, the profile form of the ward may be taken from the outside if it is desirable or necessary to make a skeleton key or "pick," by which an effective substitute for the regular key is obtained. False keys in two forms are shown on the right of the lower part of Figure 37.

Padlocks, etc.—When the head of the bolt is not to enter a box staple, but the end of the hasp forming part of the lock box, which is to be hung in a staple or ear fastened to the door-jamb, the appliance assumes the form of the padlock (*fig.* 39). Other modifications in form arise when the bolt is so changed in shape and position as to afford security from unauthorized intrusion to desks (*fig.* 40), trunks (*fig.* 41), etc.

Combination Locks.—The fact that all locks with a single tumbler are comparatively easy to open with keys other than those expressly made for them has led to the invention of the combination lock. In it the movement of the bolt can occur only after a number of movable tumblers have all been brought into certain positions; so that the misplacing of even a single one of these tumblers will prevent the bolt from moving.

In the letter lock (*pl.* 7, *fig.* 42) tumblers take the shape of rotating rings, and the letters for making the combination stand on the outside. In Chubb's lock (*fig.* 43) the tumblers are arranged as levers that rotate about a pin common to all the tumblers in the lock box, and they have perforations of a peculiar form into which a pin or dowel on the bolt penetrates. Each of these levers is brought into the position requisite for freeing the bolt by a special part of the wards of the key. It therefore assumes an irregularly notched form on the edge of the main ward, and the differences in lengths and grouping of the required notches or divisions of the ward afford facilities for easily obtaining a notable variety in locks of this kind which are alike in general features. In Price's lock (*fig.* 44) the tumblers surround the keyhole, so that the part accessible from the outside is made as small as possible, for the purpose of preventing the destruction of the lock by gunpowder. This, as well as Newell's permutation lock (*fig.* 46*a*), may be regarded as a variation of the Chubb lock, in which the divisions of the key-ward corresponding to the different tumblers (*fig.* 46*b*) can be separated, and thus interchanged (*fig.* 46*c*). By ingeniously dividing each tumbler into two parts, it becomes possible to make such changes inside the lock by a change of the key and closing the lock by its aid that the former arrangement of the key becomes useless for opening the lock. This peculiarity becomes valuable if there are grounds for suspecting that the key has been duplicated or that attempts are about to be made to manufacture a false key. Locks of this kind have been used in New York on safes in which money or valuable securities were deposited.

In Bramah's combination lock (*fig.* 45), which has frequently been used on money safes, the tumblers take the form of straight movable lamellæ, which do not directly prevent the movement of the bolt, but effect the revolution of a cylinder which acts upon the bolt through an eccentric pin. Therefore the key has no wards, properly speaking, but only a number of slots of different depths, in its tube-shaped extremity. All these and other combination locks have acquired practical value by extensive use in securing fire-, burglar-proof, and other safes (*fig.* 47).

Time Locks, now in general use on burglar-proof safes, are so constructed that the lock mechanism is controlled by a train of clock-work in such a manner that the bolts of the lock can be moved only at a given predetermined time. The controlling mechanism consists of a supplementary bolt, whose purpose is to prevent the throwing back of the locking bolts until the prearranged time, when the gearing throws out the supplementary bolt, leaving the locking bolts free to be thrown back by turning the knob. Locks on this principle are now considered the most efficient as safeguards against picking, and they are generally adopted for the protection of bank vaults, etc.

Night-latch.—With the simple forms of locks used on the doors of dwelling-houses, a dormant bolt with single or double knob is combined for use in connection with a night-latch, as shown in Figure 36 (*pl.* 7).

Yale Locks.—In the United States, a number of inventions pertaining to locks used on doors have been extensively introduced. One of the most ingenious is represented by a lock invented by the late Linus Yale, Jr.; it was first introduced about 1861, and was subsequently improved by a company engaged in its manufacture. Prior to this invention, the keys of all door locks were of a form or shape similar to that of the keys shown in connection with the illustrations of door locks described above. Leading features of his improvements in key locks consisted, first, in separating the key mechanism of a door lock from the case of the lock (which contains the bolt) and in enclosing it in a separate shell, or escutcheon, inserted from the front of the door and connected permanently through the door with the lock case behind. This made it possible to adopt a uniform size of keys for doors of all thicknesses.

The original Yale key is illustrated in Figure 1 (*pl.* 8), and the manner in which it aided to accomplish the results attained is shown in Figures 2 and 3. Figure 3 shows a longitudinal section of the escutcheon of a Yale lock. The key is shown in the lock raising the pins, or tumblers, to such heights that the joints between the two pins contained in each hole coincide exactly with the joint between the plug and its hole, leaving the plug free to revolve, and thus to actuate the lock. Figure 2 is a transverse section of the escutcheon taken through one of the pin-holes on the line *cd* of Figure 3. Figure 5 is a front view of the escutcheon, showing the keyhole and plug. When the key is withdrawn, the small brass springs press the pins to the bottom of their respective holes; so that the upper pin in each hole crosses the joint of the plug and effectually bars its motion. As the variation of one-fiftieth of an inch in the depth of any one notch of a key will so alter it that it will not open the lock to which it belongs, it is evident that an immense variety of keys can be made without duplication. This construction enabled a flat key to be used, and led ultimately to the adoption of the small and convenient form embodied in the Yale-lock key.

At a later stage of development and at a comparatively recent period the new Yale corrugated key was devised. This new key consists of the original plate key altered only by having its blade, or portion which enters the lock, corrugated in longitudinal lines. By these apparently simple means and a corresponding change in the form of the keyhole, it is claimed that notable additions have been made to the advantages possessed by the original Yale lock. They include, among other things, these qualities—namely, the lock cannot be operated by any key but its own; it cannot be picked except by some tool which will raise the tumblers, and it is alleged that the shape of the keyhole renders it impossible for any tool to raise the tumblers; should an unauthorized person temporarily get possession of the key, he would be unable to have a duplicate made, because the corrugated key, shown in Figure 4 (*pl.* 8), must conform to the exact contour of its keyhole, shown in Figure 5, with an accuracy attainable only by the use of special and expensive machinery.

Figure 12 exhibits the Yale standard front-door lock, with section removed to show the operating mechanism. The ordinary street-door lock, combining bolt and night-latch, requires two keys, but in this improved form of lock only one key is necessary, both bolts of the lock being controlled by a single key; so that its possessor can never be locked out. Another key is furnished with the lock intended for the inside locking of the main bolt only, but this key will not operate either bolt from the outside.

Figure 16 illustrates a form of concealed bolt which is mortised into the edge of the door-leaf, and is operated by a metal thumb-piece.

The Door Check and Spring (*fig.* 6) is a simple and effective device for automatically closing the doors of apartments and for preventing the annoyance caused by their slamming. It consists principally of a spring the strength of which is gauged according to the resistance presented by the door to which it is attached, and a cylinder furnished with a piston, the latter being set in motion by the movement of the door in opening and closing, and provided with a valve which permits the air to enter the cylinder freely when the door is being opened, but which closing exhausts the air more or less according to the force exerted in the operation, and thus acts as an air-cushion, bringing the door to a stop for an instant just before the point of closing, when, as the air pressure is equalized, the tension of the spring quietly closes and latches it. The device is provided with suitable brackets, adapting it to be attached by one to the frame over the door and by the other to the top of the door itself.

VII. CHIMNEYS.—HEATING AND VENTILATING APPARATUS.

The objects named in the heading take rank among the most important in the whole domain of building construction, and their consideration involves peculiar difficulties, as it must involve other departments of science. This treatise will be restricted, however, particularly in regard to the apparatus for heating, to the proper selection of methods, and to a general inquiry into the conditions demanded for successful application. Chimneys are, indeed, parts of heating apparatus, but a separate consideration of them is justified for the reason that their arrangement does not depend upon the special purpose for which they are built, and because the chimney forms an integral part of the entire building, while heating apparatus is frequently a separate adjunct. The means employed for heating and ventilation will be considered together, on account of the close natural connection between them, and also because they are generally in actual union.

Chimneys are built for the purpose of carrying off the products of combustion, such as carbonic oxide, carbonic acid, steam, the incombustible portions of fuel, etc., and also of introducing the necessary amount of atmospheric air, or oxygen, needed in the process of combustion. The quantity of product to be carried off must regulate the inner dimensions, or cross-section in the clear, and also, indirectly, the height of the chimney. The outer dimensions, however, must depend entirely upon considerations of construction, such as stability, material, relative position, safety against fire, and architectural elegance.

Draught.—The upward tendency of the air current within the chimney—called the "draught"—is caused by the direct effect of a column of specifically heavier atmospheric air of equal height on the outside of the chimney upon the column inside, which is rarefied by the heat, and is therefore specifically lighter. Apart from such hindrances to its passage as the friction of the walls, etc., the draught is increased in force by the additional height of the chimney and the difference in temperature between the inside and the outside column of air. The product of the speed of the draught and the size of the cross-section will give the volume carried away in a given unit of time, and, inversely, the size of the cross-section must depend upon the speed or strength of the draught and the quantity of smoke to be carried away. If the chimney has a cross-section larger than the smoke-flues of the heating apparatus or of the opening for atmospheric air, the force of the draught will be proportionally retarded. In other words, narrow chimneys draw better than wide ones.

The distinction between factory chimneys and those in ordinary buildings must be clearly marked. The latter have cross-sections of regulated size, and a height also regulated by the character of the building; so that the number of chimneys must be proportioned to the volume of the product to be carried away. In factories, on the contrary, the dimension of the chimney is varied according to the demand made upon the boiler furnaces for steam-power.

Chimneys for Ordinary Buildings are usually of two kinds, one being of such width that it can be entered, the other being the narrow, or Russian, chimney. In the former, the cross-section is at least 15¾ inches in the clear and the walls one brick, or 4.7 inches, thick. The Russian chimney is generally preferred, as the air can be more quickly and uniformly heated, and as it can be introduced into the walls without occasioning a projection or chimney breast. It also requires less framing in the floor joists and beams, takes less space, and is easily cleaned, a broom weighted by a ball and suspended to a line being used for the purpose. The cross-section of the Russian chimney is generally circular and 7½ inches in diameter. In many countries—as in Saxony, for instance—the bond of the courses is arranged as in Plate 10 (*fig.* 1). The bricks employed are of the size used in the walls—that is, 9.8 inches long by 4.7 inches wide and 2.5 inches thick. A circular notch of 1 inch depth is made on one of the long sides of the brick, as seen in the Figure, reducing the wall to a minimum thickness of 3.7 inches. A chimney built in this manner can carry off the smoke of three ordinary stoves, and can be built without a chimney breast in a brick wall 15 inches thick, a slight departure from the vertical direction being admissible.

Caps.—Chimneys are often covered with a plate having a corresponding opening or terminated by a more or less ornamental extension of sheet metal, as in Figure 9 (*pl.* 2), and are carried above the ridge of the roof to such a height as will assure the carrying off of the smoke. Further to assist this process, and particularly to nullify the effect of unfavorable winds, chimney tops are frequently set on. They are either movable or stationary. Figure 2 (*pl.* 10) exhibits a movable one, consisting of a metal pipe the width of the chimney fastened in such a manner that it can revolve and ending in a funnel opening sideways. It also carries a vane made as large as possible. As the wind blows, the vane causes the top to turn so that the mouth of the funnel is directed away from the wind. A rarefaction of the air thus occurs directly in front of the opening, suction is induced, and the draught upon the smoke is increased. The only defect in this construction is that a sudden change in the direction of the wind may affect the mouth of the funnel and interfere with the outlet of the smoke. The chimney top also requires careful attention, that it may always be in condition to move freely. In this respect, the stationary tops are more reliable. Figures 3 and 4 exhibit examples of the latter. The object in this case is to break the direction of the wind so that it is deflected toward the top, inducing suction. In the example shown in Figure 3, a conical screen of metal is combined with a cylindrical metal pipe which is placed either in or upon the top of the chimney.

Deflector.—Figure 4 shows the patent cap, or top, invented by Windhausen and Büssing of Brunswick, and called the "deflector." The screen, as shown in the cut, is more sloped, and is surrounded by a peculiarly shaped case with openings on the lower edge for the admission of air; the upper part stands out in such a manner as to allow the wind to enter and assist in getting rid of the smoke. The other parts of the apparatus, such as the flat cover in Figure 3 and the funnel hung in the casing and furnished with small pipes as in Figure 4, serve to hinder the entrance of rain, and also to prevent the chilling of the air within the chimney.

Factory Chimneys are built either square, octagonal, or circular on both the outside and the inside, or occasionally with an octagonal form on the outside while circular on the inside. As great height is required, not only to induce the necessary draught, but also to prevent annoyance from the smoke, they generally tower above the surrounding buildings, and are built tapering, in order to insure greater stability.

The taper usually extends through about one-twentieth of the full height of the chimney, and on both the outside and the inside. Thus a chimney 98½ feet high with an upper wall 9.8 inches thick will have a lower wall of from 19.7 to 21.7 inches in thickness. As a rule, when the chimney is circular, requiring wedge-shaped bricks, the wall may be thinner than the other forms. The thickness of the lower wall of the chimney need not bear any special proportion to the pediment, which is almost always seen in factories, and is generally square in cross-section with thicker walls. The tapering on the inside is done either at certain sections or continuously, but care must be taken that the upper diameter on the clear is not too small to permit the free passage of the smoke.

It is impossible here to consider in any way the proportions of the quantity and pressure of steam or the number and capacity of boilers in relation to the height of chimneys. Being generally built of brick, factory chimneys are readily ornamented at the top. Figure 5 (*pl.* 10) exhibits one with an octagonal cross-section; Figure 6 shows one of a circular cross-section with the corresponding arrangement of its pediment. As the illustrations indicate, pleasing effects are obtained by the introduction of specially shaped and tinted bricks. Some of these structures are notable for their great height. The loftiest chimney (454 feet high) in the world, and one of the highest masonry structures, was built at Port Dundas, Glasgow, Scotland, in 1857–1859. There are only two church-steeples in Europe that exceed it—namely, the Cologne Cathedral (510 feet) and that of Strasburg (468 feet); and but one loftier structure in America—namely, the Washington Monument (550 feet). A few of the most prominent factory chimneys, arranged in the order of their height, are named in the following table:

COMPARATIVE HEIGHTS OF THE PRINCIPAL TALL CHIMNEYS.

	Height in Feet.
Glasgow, Port Dundas, Scotland, F. Townsend	454
Glasgow, St. Rollox, Scotland, Tennant & Co.	436½
Halifax, Dean Clough Mill, Scotland, Messrs. Crossleys	381
Lancashire, Bolton, England, Dobson & Barlow	367
East Newark, New Jersey, United States, Clark Thread Co.	335
Barmen, Prussia, Germany, Wessenfield & Co.	331
Edinburgh, Scotland, Gas-works	329
Huddersfield, England, Brook & Son, Fire-clay Works	315
Smethwick, England, Adams Soap-works	312
Carlisle, England, P. Dixon & Son	300
Bradford, England, Mitchell Brothers	300
Greenhithe, Kent, England, J. C. Johnson	297
Lowell, Massachusetts, United States, Merrimack Manufacturing Co.	283
Dundee, Scotland, Camperdown Linen-works, Cox Bros.	282
Creusot, France, Schnieder & Co.	280
Lancashire, England, Barrow-in-Furness Hematite Iron Co.	259
Bradford, England, Manningham Mills, Lester & Co.	256½
Manchester, New Hampshire, United States, Amoskeag Manufacturing Co.	255
West Cumberland, England, Hematite Iron-works	250
Lancaster, England, Story Bros.	250
Cheshire, England, Connahs Quay Chemical Co.	245
Bradford, England, Newland's Mill	240
Lawrence, Massachusetts, United States, Pacific Mills	233
Harwich, Dovercourt, England, Pattrie & Sons	230
Woolwich Arsenal, England, Shell Foundry	224
New York City, New York, United States, New York Steam Heating Co.	221
Northfleet, England, F. C. Gostling & Co.	220
Ivorydale, Ohio, United States, Proctor & Gamble	218
Lawrence, Massachusetts, United States, Tower Pacific Mills	215
Dewsbury, England, Olroyd & Sons	210
Lanarkshire, Scotland, Coltness Iron-works	210
Wilmington, Delaware, United States, City Water-works	204
Philadelphia, Pennsylvania, United States, Finley & Schlechter	202
Lamokin, Pennsylvania, United States, John M. Sharpless & Co.	200

Heating and Ventilating Apparatus.—The direct object of all heating apparatus is the production of warmth, but the different uses to which this product is applied necessitate great variations in the mechanical details. The methods by which heat is utilized for the transformation or combination of diverse materials in different industries will not here be considered, as they belong more directly to mechanical or chemical science; the present examination will, therefore, be restricted to the appliance of heat to the particular requirements of the rooms of buildings and for culinary purposes. The apparatus for heating rooms is of necessity intimately connected with the methods for securing ventilation or with the arrangements by which a free circulation and change of air are maintained in closed apartments.

Object of Heating Apparatus.—The first object in heating is to raise the air contained in the apartment to a given temperature, and afterward to maintain it at that point against the loss of heat from the entrance of cold air through windows and doors, and also from the effect of the conducting surfaces of walls, ceilings, floors, and especially glass. The generation of the heat is accomplished frequently in a suitable apparatus contained in the room, the heat being transmitted directly from the walls of the apparatus or from the hearth itself to the air of the apartment. By another arrangement, means are provided for conducting the heat from apparatus outside the room, and this is done by air, water, or steam. The warming of the air of a room is produced by circulation when no change of air is required, and this circulation, or movement, is maintained by the rising of the particles of air near the source of the heat as they become rarefied, while the particles coming in contact with the walls and windows, being cooled, become specifically heavier and sink in a corresponding degree.

Heating Apparatus generally consists of a fire-box or a hearth upon which the combustion takes place, the floor being made of a grating with openings, to allow the passage of the incombustible portion of the fuel and the access of the fresh air necessary to the support of combustion. From the fire-box the gaseous products pass through longer or shorter channels or flues to the chimney, giving out in their passage the greater part of their heat to the walls of the apparatus; while another portion of the produced heat serves to create the draught of air necessary to supply the combustion.

Fireplaces or Open Hearths.—In the mechanical contrivances contained within the room itself, a distinction must be made between fireplaces and stoves. In fireplaces, as seen on Plate 10 (*fig.* 7), the apparatus is open toward the space to be warmed and the heating is mainly accomplished by direct radiation. This plan is objectionable on the ground of economy, as the greater part of the heat must escape through the chimney; but the arrangements can be made highly decorative and attractive for domestic uses, as is seen in the illustration. The grate, ash-pan, and communication with the chimney are exhibited in cross-section.

Open fireplaces adapted for burning gaseous fuel have lately come into general use in several localities in the United States. The gas is permitted to escape from numerous small orifices in pipes laid on the base of the fireplace. Designs in the form of logs of wood are sometimes introduced by way of ornament. They are considered to be in many respects far more desirable than any previous appliances devised for an open fire.

Stoves: Classification.—Stoves—at least, for the warming of living-rooms—are much used, and there is a great variety not only in forms and sizes, but also in the principle of construction and in the material employed, as will be seen in the examples shown on Plate 10. According to the principle upon which the heating is to be done and the form of construction affected, a distinction must be made between stoves for temporary or intermittent heating, as in Figures 8, 9, 10, and 14, and those intended for continuous heating, as in Figures 11, 12, and 13. Stoves without ventilation are exhibited in Figures 8 to 11, and those with ventilation, or jacket stoves, in Figures 12 to 14. Distinguishing them by the material employed, those made of iron are seen in Figures 8 and 10 to 14, while the clay or tile stove is presented in Figure 9. Also, in a classification by shape, round stoves are presented in Figures 8, 13, and 14, and four-cornered stoves in Figures 9, 10, 11, and 12. The dimensions depend mainly upon the size of the room, but also upon the surfaces producing the chilling of the air, as well as upon the material, thickness, and position of the walls and ceilings. Many stoves are suited for the consumption of only a certain kind of fuel, such as those in Figures 11 and 12, intended for brown coal, the one in Figure 13 being suited to coke. The other forms can be used not only for the fuels already mentioned, but also for hard coal, wood, peat, tar-cake, etc. In explanation of the illustrations, it may be added that the barrel stove, seen in vertical section in Figure 8, is one of the most imperfect forms, the distance from the fire grate to the chimney being very short, and the consequent loss of heat very great unless the distance be increased by lengthening the stove-pipe. These stoves are made on a small scale, and are used only where a rapid and temporary heat is required.

The Tile Stove, seen in Figure 9, has horizontal, and sometimes vertical, flues, as in the vertical section *c;* a relatively larger heating surface is thus obtained. The Figure exhibits the middle partition of each of the horizontal flues for affording additional length, seen vertically in *b*. The combustion takes place in an iron box enclosed in tiles. (Vertical sections, *b* and *c;* horizontal section, *g*.) Cornices near the top and the base are placed on the outside, rendering the stove more or less ornamental; the material differs in quality and may be with or without glazing. Faïence stoves, composed of the best white kaolin finely glazed, are elegantly ornamental, and the Berlin stove is also of this class.

The Iron-stage Stove, shown in Figure 10, has also horizontal flues, but with vertical connecting pieces, forming the heating tubes; the heat is very quickly transmitted, but it is not lasting. The fuel is introduced through one of the narrow sides seen at *b*. Stoves of this shape are made of burnt clay with iron casings.

The Self-feeding Stove, for brown coal (*pl.* 10, *fig.* 11), affords a continuous heat as long as the magazine is kept supplied. This magazine forms the vertical middle part, seen in front view at *a*, and is supplied by the charging hopper, seen in side view at *b*. The receiver stands below, in direct connection with two hearths; so that when the fire is burning fresh fuel is supplied to them, the amount being increased when the fire-grate is set in motion by the handles on the outside. By this motion the spaces between the bars of the grate are cleaned of the ashes, which fall into the ash-pan. To prevent the ignition of the entire stock of fuel in the supply-box, the hopper must be hermetically closed. The flues of the stove proceed first from the hearth in a curved direction, then vertically upward by the side of the supply-box, uniting above the latter, and thence by a common trunk into the chimney. The steady and continuous stream of heat renders the self-feeding stove particularly useful for large and exposed apartments.

The Jacket Stove—also self-feeding—shown in horizontal and vertical section in Figure 12, was constructed by Civil Engineer E. Kelling for the Lying-in Institute in Dresden. In principle it resembles the foregoing, but differs in form, being arranged for ventilation, and therefore provided with a jacket. The fresh air from the outside enters through the duct (*o*) into the interspace between the stove and the jacket, becomes heated by contact with the heating surfaces of the stove, and, as the jacket is open at the top, streams out into the room. There is no arrangement in this stove for getting rid of the foul air, which must be provided for in other parts of the room. If no change of air be desired, the fresh-air opening is closed by the slide (*L*), and another one—not exhibited in the Figure—at the foot of the jacket, is opened, so as to allow the air of the room to enter, and thus induce a circulation. The cut also shows the outside and inside doors (*A*) for filling the supply-box with coal; slide (*B*) for cutting off the supply-box from the fire-box; horizontal grate with movable raker (*C*); trap (*D*) to allow the ashes and cinders to fall directly into the ash-pan; air cylinder (*F*) for cooling the fire-plate and supply-box; evaporator (*G*) for maintaining the air at a fixed degree of humidity; caps to cleaning openings (*H*, *H*); valve (*E*) for directing the smoke directly into the chimney from the one vertical smoke-pipe, as is necessary in stormy weather, or for leading the flame into the three vertical pipes.

The Self-feeding Coke Stove with jacket (*fig.* 13) is constructed on the same principle as the one just described, as regards both heating and ventilation; the manner in which it is finished is, however, essentially different. The reservoir, or filling hopper, for the coke is circular in section, tapers as it rises, and is closed by means of a cover with a sand calk while combustion is progressing. The smoke-pipe, ring-shaped in section, is carried around the charging hopper, and is connected below with the fire-box by a slit that passes entirely around, while it is connected above with the chimney. Outside the smoke-pipe, and concentrically with it, lies the perforated jacket; into the space between, the air from the outside is introduced through a channel below, and it comes out heated, above, into the room. The top of the stove has a movable cover and is made to hold a vessel of water.

The Regulator Stove with jacket (*pl.* 10, *fig.* 14) serves for ventilation like the one just described. The air enters the space between the stove and the jacket when the valve (*c*) is opened, and when heated issues through *a* into the room. When ventilation is not desired, the valve (*c*) is closed, and another valve, on the right, at the foot of the stove, is opened instead, as is seen in the cut of the exterior of the stove. The valve (*a*) in the stove itself serves, when set diagonally, to direct the fire into the chimney, the lower stove door being opened, as seen in the cut, so as to conduct the air of the room over the burning coal, as in a fireplace. In regard to the regulation—which can also be done as well in other stoves—a slide in the lower door is opened or closed, so as to admit the required amount of air to support the consumption of the coal. The upper door is considerably above the grate; the fuel is heaped in to the same level through this upper door, and is kindled with wood. During the kindling the whole of the lower door may be left open; it is afterward closed and the regulating done by the slide.

American Stoves.—In the United States, an immense number of stoves, heaters, ranges, and furnaces are manufactured, and many devices have been introduced. Changes are frequently designed in various details, and arrangements are promptly made to provide for all well-defined requirements based on differences in the kind or quantity of fuel to be consumed, the amount of heating effect to be produced, the extent to which ornamentation is desired, etc. Inventive genius and manufacturing enterprise have been active in all branches of heating apparatus, and particularly in connection with stoves or ranges used for cooking. There are also a large number of parlor stoves or heaters used exclusively for heating in parlors, sitting-rooms, or bed-rooms, and many kinds of furnaces used in heating air transmitted from cellars to rooms in the upper stories of dwellings.

Figure 7 (*pl.* 9) exhibits a form of an American base-burning coal stove, with section removed to show the interior arrangement of the magazine, or supply-hopper, and fire-grate. A popular form of heating apparatus is the Franklin stove (*fig.* 8), which combines the sanitary advantages of the open fireplace or grate with the economical heating effect of the closed stove, or hot-air furnace. A modification of the Franklin stove has the open-grate fire with provision for warm-air circulation. It may be used, therefore, for heating several apartments by a suitable arrangement of hot-air flues. A convenient adjunct to either a stove or a hot-air furnace is that shown in Figure 6. This consists of an extension of the smoke-flue to the floor, at which point it is perforated with suitable openings to admit air. The pipe leading from the stove is provided with a damper, as is also the extension-pipe. By closing the door of the stove or furnace and partly shutting off the damper in the stove-pipe and opening the damper in the auxiliary flue, the draft will be so controlled as to maintain the fire in moderate activity for a long time. A reversal of these operations quickens the fire. By this improvement the heating apparatus can be perfectly regulated without opening the fire-door.

The forms of heating apparatus in which the heat is generated outside the room are extensively used at the present time for public buildings as well as for private dwellings. According to the means employed, these methods are known as "hot-air," "water," or "steam heating."

Hot-air Heating is accomplished by air warmed in a special chamber by a stove or heater and conducted by flues to the room where it is needed. The cool air of the room may be taken back to the heating chamber through downward flues, or channels of circulation, to be warmed again, or through ascending flues, or channels of ventilation, upward to the open air. In the latter case, fresh air from outside must be supplied to the heating chamber. The heater and flues may be arranged in a variety of ways. Figures 15 and 16 (*pl.* 10) represent the hot-air heating apparatus constructed on correct principles by the above-mentioned Engineer Kelling. The lower parts of the cuts show the heating chamber (*A*), in both cross- and longitudinal-section, and the heater, which consists mainly of cast-iron tubes (*B*). The former is divided by partitions into sections, according to the number of the rooms to be heated and the amount of heat likely to be lost in them. For cold air, each section has an opening (*f*) below, which communicates with the main duct (*c*); and for the heated air above, a corresponding opening, which communicates with the hot-air flue. The fire is self-feeding. In Figure 16, *l* is the receiver for fuel; *K*, the fire-grate, in steps, with horizontal grate beneath; *i*, raker for removing ashes; *m*, turn-plate in the smoke-pipe leading to the chimney; and *gg*, caps for cleaning openings in heating flues. To assure moisture to the air, an evaporator, seen at *c* (*fig.* 15), is set parallel to the heating flues and adjusted from the outside. The manner in which the heating is done is seen in the upper part of the Figure, where *a* is the register; *d*, damper for summer ventilation; and *c*, damper for spring and autumn. The double damper (*b*), when the other dampers are rightly adjusted, effects circulation when lifted and ventilation when lowered. The following directions, prepared for the use of this heater, will complete the explanation: 1. For kindling the fire: *a* open; *b* lifted; *c*, *d*, *f*, closed. 2. For winter ventilation: *a* open; *b* lowered; *c*, *d*, closed; *f* open. 3. For ventilation in spring and autumn: *a* closed; *b* lifted; *c* open; *d* closed; *f* open. 4. For summer ventilation: *a* closed; *b* lifted; *c*, *f*, closed; *d* open; windows open.

Hot-air Heating in the United States.—A large proportion of the dwellings located in cities and populous towns in the United States are heated by air warmed in furnaces, usually located in cellars, and numerous devices are used in connection with such systems. Physicians and sanitary engineers as a rule regard them as deleterious to health, and especially to those who are closely confined and when the ventilating apparatus is defective.

Furnaces of considerable size and heating capacity are commonly brick-cased—an arrangement which greatly facilitates the proper setting of the furnace, and which is desirable on the score of economy, as the masonry aids substantially in preventing the wasteful conduction of heat. Figure 9 (*pl.* 9) illustrates an improved brick-set furnace with a section cut away to show the construction, and Figure 10 exhibits one of the more common forms of furnaces usually called "portable heaters." A belief that there are more agreeable and wholesome modes of heating dwellings is leading to changes in prevailing practice, some of which are in the direction of a return to open grates, and others toward the use of systems of heating by hot water or by steam.

Hot-water Heating depends upon the circulation of hot water through pipes, the heat being communicated to the air of the room by the walls of the pipes. The chilled air, being specifically heavier, causes the ascent of the warm water, which is specifically lighter. This is accomplished by two methods—one known as "high pressure," the other as "low pressure." In the low-pressure (*pl.* 10, *fig.* 17), the water is raised to the boiling-point. In the high-pressure system (*fig.* 19)—also known as Perkins' method, from the name of the inventor—the water is raised above the boiling-point, and for this reason the system of pipes must be entirely closed.

Low-pressure Water Heating.—In low-pressure water heating, after the water is heated in an iron or a copper boiler, it proceeds through a flow-pipe—covered, to prevent chilling—first into an expansion vessel near the roof of the house and open at the top, and is thence distributed through pipes to the different stories and rooms, where the heat is given off either by the walls of the pipes or by radiators; the water then returns to the boiler. Figure 18 gives two sectional views of one of these radiators as used in a parish school in Berlin. It consists of a wrought-iron cylinder of 2.1 feet diameter, and is provided with a number of inner pipes, into which the air of the room enters from below and emerges at a higher temperature above. The warm water, on the contrary, enters the radiator above and leaves it below; so that the heat is given off by the walls of the large cylinder as well as by those of the small air-pipes. The supply of water can be regulated or cut off entirely by cocks. If ventilation is also to be provided for, the air-pipes of the radiator must be brought into direct connection with a duct for fresh air below.

High-pressure Water Heating—Perkins' system—is shown in Figure 19. The flow-pipes are seen at *a*; return-pipes, at *b* and *c*; and the closed expansion-pipe (*m*) is shown at the upper end. A cock (*n*) is also placed at the highest point; this must be open while the water is being forced in, to allow the air in the pipes to escape, while it also allows the passage of the water. A little evaporation always occurs during the heating, on account of the heavy pressure and the porosity of the iron. These pipes must be of wrought iron, and of narrower calibre than for low-pressure heating, on account of the pressure of the superheated water. For the same reason, boilers and radiators are not used in this system, their places being supplied by coils of pipe, of which one (*A*) is shown at the furnace and two others (*B*, *C*) in the rooms. As the length of the pipes is limited and ought not to exceed 820 feet, several systems with an equal number of coils are used. The latter receive heat, as shown in Figures 19 and 20 (*pl.* 10), from furnaces built of brick, a single fire generally serving for two coils.

The furnace designed by Engineer John Haag of Augsburg for the insane asylum at Neustadt-Eberswald is represented in Figure 20: *a* is the front; *b*, vertical section; *c*, cross-section; *d*, ground-plan, taken horizontally over the grate. In the elevation (*a*), the doors for making the fire and for the ash-pan are seen in the middle, above and below; the pipe connections for the corresponding coils, at the right and left; the flow-pipes, at the outer ends above; and the return-pipes, nearer the inside and going farther down. A supply-pipe over the point *a*, proceeding from a force-pump, is connected with the latter. In the longitudinal section (*b*) the fire-grate, lying well elevated, is seen in the middle. The gases produced by combustion proceed from the grate through openings in the two partitions, then through the coils downward to the common smoke-flue, which is provided with a damper. The lighter-tinted portions of the sections and ground-plans represent fire-brick. No further explanation will be necessary for Figures *c* and *d*.

Gurney System of Hot-water Heating.—There has been carefully developed an American system of hot-water heating—called the "Gurney system" (*pl.* 9, *figs.* 2, 3, 11)—which is intended to serve as a substitute for steam heating in hotels and large buildings in which it is extensively used, and also for service in dwellings. A description of its advantages includes claims that hot-water radiators will heat with a low fire, and will continue to give out heat not only as long as there is any fire under the heater, but also after the fire is completely extinguished and until the water in the apparatus becomes of the same temperature as that of the surrounding atmosphere. It is alleged that the hot-water radiators can be perfectly controlled and regulated by partly closing the supply valve; that there is no danger from explosion, and no waste of water; that the consumption of fuel is less than by any other mode of heating; that equality of temperature is maintained throughout all parts of the building; that the apparatus is so safe and simple that an ordinary domestic is competent to take charge of it; that it costs little or nothing for repairs and is considered very wholesome for dwellings.

Steam Heating closely resembles low-pressure water heating. The steam, which is generated in a boiler, proceeds through a well-covered supply-pipe to the transmission-pipes in the rooms. In these pipes, which are generally of copper and rather large, the steam is again condensed into water by the loss of heat and returned to the boiler by a special pipe. As a substitute for such arrangements radiators can be used, as in the hot-water heating system. Figure 21 (*pl.* 10) shows one which was erected for the baths at Elster, in Saxony, by Engineer E. Kelling. It has an exterior and an interior cylinder; between them is the steam box (*d*), to which the steam is conducted by the pipe *a*, from 0.6 to 0.8 of an inch calibre, while the condensed water drains off through the pipe *c*. The steam enters the shut-off space (*e*) at the top through the pipe *a*. This space (*e*) is provided with an air-valve and contains a receptacle (*g*) which is thus warmed, as well as any bath linen which may be placed in it. The condensed-water pipe (*b*) as it leaves *e* unites below with the pipe *c*. By means of the valve (*K*) the apparatus can be utilized both as a ventilating and as a circulating stove. In the former use, the fresh air enters the room when the valve is lifted; in the latter, the valve being lowered, the air of the room circulates through the inner cylinder.

American Steam-heating Systems.—In the United States, steam heating has been extensively used in connection with the heating appliances of hotels, factories, and various other buildings in or near which steam-engines are located. One of the general effects of the numerous applications of this description has been the discovery of the causes and remedies of various defects or deficiencies and the invention of numerous desirable adjuncts. There is a wide diversity of views regarding the relative merits of hot-water and steam-heating systems, which latter are being extensively introduced in various cities—especially in New York and Boston—where a large number of dwellings and shops or working-rooms are supplied with steam from one or more common centres.

Steam-heating Companies.—The protracted and successful efforts made to extend these steam-heating systems over miles of streets have disclosed the nature of the practical difficulties to be encountered and led to the adoption of devices for surmounting them. The results reached and the advantages claimed, as described by the engineer of the New York Steam Company, Mr. Charles E. Emery, are as follows: "It will be understood that steam-engines of all kinds and sizes in any location from cellar to garret can be operated to drive shops, furnish electric light, pump water, and the like, and that heating, either by live or exhaust steam, can be done on any scale; but it is also true that nearly all the cooking of a family can be done by steam. Nothing is lacking, in fact, but sufficient temperature to brown bread and put the finishing-touch, as it may be called, on broiled meats. . . . . With steam stoves fitted with various devices and having in connection therewith small gas stoves for finishing the broiling of meat, and perhaps gas attachments to the ovens to brown the bread and cake, housekeepers will be provided with a great boon. With the exceptions named, which do not form a large portion of the work, every operation can be performed by simply regulating a steam valve. By these means the objectionable features of handling coal and ashes will be entirely removed, and provision for doing most of the cooking, as well as complete facilities for heating water, and in winter for warming the building, be provided 'on tap,' so to speak, the same as gas and water."

Gas Heating differs essentially from all the methods previously treated, for, although the heat is conducted through pipes, the generation of the heat—that is, the combustion of carburetted hydrogen, or burning-gas—is effected in stoves standing in the rooms to be heated. No chimney is used with this apparatus, and the air becomes unfit for respiration unless some means of free access to a chimney is devised. Figure 22 (*pl.* 10) is one of Elsner and Stumpf's gas stoves as constructed by them in Berlin. It is open in front, and has twenty-four burners, each burner being one foot long. The heat from the burning gas is communicated to the air of the room in part directly, and also indirectly through the walls of the stove, as well as by the diagonal plate on the inside. In the houses and cities located in the natural-gas regions of the United States, this fuel is universally employed for domestic as well as industrial uses, and with most satisfactory results.

In conclusion, it may be said that several of these systems of heating may be combined. The entire apparatus may be constructed as for hot air, while the air supplied may be heated by passing over steam or hot-water pipes in the heating chamber instead of in the heater, or by the method of steam heating, with the difference that the steam does not give up its heat directly to the air of the room through the walls of the pipes, but in the first place to water inside of a water stove.

Apparatus for the Preparation of Food, either by roasting, by stewing, or by boiling, vary greatly in size and special fittings, and also in the method by which the heat is generated. The size depends mainly upon the number of articles to be prepared, and the special fittings depend upon the customs of the country and the habits and relations of the family. The heating may be produced by common fuel—such as wood and coal—by steam, or by gas. Figures 23 and 24 give examples of apparatus of the first kind upon a small scale, for domestic use; Figure 25 shows the same arrangement of larger size, for the purposes of a public institution; Figure 26 exhibits a large steam-cooking apparatus, also for a publie institution; and Figure 27 shows a small portable gas apparatus intended for family use.

Cook-stoves and Ranges.—The arrangement shown in Figure 23 is constructed of iron, and consists of a small fire-box or range, with a cooking or roasting stove, two ovens, and a water-back. The single fire is on one of the shorter sides of the range; so that the burning gases pass underneath the top of the range to the cooking stove proper, where they come in contact with the walls of the ovens on all sides and with the water-back on one side, proceeding thence to the chimney. The top is provided with rings and openings by means of which iron cooking vessels are brought in direct contact with the fire, as is shown in Figure 24 in vertical section. But the cooking vessels are often set upon the top with no opening. The range is 9½ inches high, about 11 inches wide, and 13 inches long, and the stove containing the ovens 4 feet high, 11 inches deep, and 13¾ inches long. Similar apparatus are built of masonry, with or without tile facing.

The varieties of cooking appliances in the United States are legion, and they display great ingenuity in design and construction. The development of the heating apparatus for cooking from the primitive open fire-place to the modern coal stove and range exhibits remarkable advancement in this department of invention. The cooking apparatus in general use in cities for domestic service is the brick-set range, of which well-known and improved forms are shown in Figures 4 and 5 (*pl.* 9). Ranges are usually provided with a "water-back," or boiler, to afford supplies of hot water for the use of the household; the most recent form of the kitchen range is furnished with an improvement termed a "circulating boiler," which insures an increased supply of hot water.

The cooking arrangements for the prison at Antwerp—of which Figure 25*a* (*pl.* 10) shows the exterior—are built in a sort of recess, over which, as is seen in the sections *b* and *c*, wide flues are constructed, to carry off the vapor and ventilate the kitchen. Of the three kettles, two are used for preparing food, and the third contains the water to be warmed for kitchen use. The setting of hollow copper rings outside the kettles is peculiar. They are connected with flow- and return-pipes, which lie in the ventilating flues of the building, and, like these pipes, are filled with water; so that the ventilating flues are warmed when the kettles are used.

The Steam-cooking Apparatus seen in Figure 26 is that of the Insane asylum at Neustadt-Eberswald, and, like the high-pressure water-heating apparatus of the same institution, was constructed by Engineer John Haag of Augsburg. The kettle, or boilers, made of copper, have their lids counterweighted and are suspended by tight-fitting joints in hemispherical jackets. The steam from the main steam-pipe (*a*), shown cut through in Figure 26*b*, enters the space between the boiler and the jacket through the connecting-pipes (*c*); *d*, *d*, are the pipes for the condensed water, opening into the main pipe, *b*; *x*, *x*, are air valves, to be opened for the entrance of the steam, and then closed; *f* is the cold-water supply-pipe for the boilers; finally, *e*, *e*, are flue-pipes leading to a ventilator, to carry off the fumes of the cooking. The whole is surrounded by an iron casing.

Portable Gas Stoves.—The small portable gas-cooking apparatus shown in Figure 27 consists of a sort of tripod upon which is placed the vessel to be heated. Inside the tripod are the gas-burners, connected with a piece of gas-pipe so arranged on the outside as to make a convenient handle. The gas is brought to the apparatus from the mains by means of an india-rubber tube. Figure 1 (*pl.* 9) shows a recent form of cooking range heated by gas. This is an American apparatus which is growing in popularity.

Oil Stoves are in very general use for heating and for culinary purposes. Where perfect combustion of the oil is insured, the result is a pure white flame and intense heat without smoke or odor. These stoves are adapted to give, during early autumn and spring, a sufficient warmth to rooms which would be overheated by furnaces or stoves. Being placed on rollers, they can easily be moved from one room to another, and require no more care than an ordinary house-lamp. Stoves heated by gasoline—one of the products of petroleum—are adapted to the same uses as oil stoves. The gasoline stove is practically a gas stove.

VIII. PRIVATE AND PUBLIC BUILDINGS.

Under this head will be considered edifices erected for special and practical purposes in which the elegance of the architecture is only incidental to the object in view. Such structures will be excluded as would come under an agricultural classification, including stables, barns, etc., also railroad buildings (which will be considered under Engineering, Part II.), factories, or buildings erected for military purposes. The structures selected for consideration will be those intended for private use or for strictly public purposes.

1. Types of Dwellings.

The art of construction is traceable to practically similar beginnings among all peoples. While it is doubtless true that primitive man found frequent shelter in caves, in hollow trees, and in thick underbrush, as do many of the lower animals, it is equally true that like the latter he is naturally a home-building animal, and the instinct that Nature has so generally implanted in its animate creations finds in man, as do all the instincts of the lower animals, a higher and an æsthetic development.

The earliest habitations of primitive man, such as caves, rock-shelters, or grottos, need scarcely be considered in connection with our present subject, falling as they do more properly within the province of ethnology. In historic times, among all races, in hyperborean latitudes as also in equatorial regions, the crudest human habitation specifically constructed as such has taken the form of a hut.

The Tent, or movable domicile constructed by man in the nomadic and pastoral stage of progress, is generally a prototype of the more permanent dwellings constructed by the same races in their settled condition. In fact, ethnological research has clearly indicated that the architecture of any given people, as expressed in its temples and palaces, may be considered, both in its outward character and in its principle of construction, as but the crudest form of the simple domicile developed to a stage commensurate with the national progress. The tent consisted in its simplest form of a covering of skins or cloth stretched over a framework of cords and poles and fastened tightly to the ground by pegs. From the earliest historic times tents have been used for purposes of shelter. We read (Gen. iv. 20) that Jabal "was the father of such as dwell in tents and have cattle." From the first their use has been associated with pastoral life, whose requirements lead to frequent removals in search of water and pasturage. The first tents were undoubtedly covered with skins (Ex. xxvi. 14), but nearly all the tents mentioned in Scripture had coverings of woven goat's-hair (Ex. xxxv. 26; xxxvi. 14), as have the tents now used in Western Asia; hence it was that "the tents of Kedar" were "black" (Cant. i. 5).

Figure 5 (*pl.* 12) is a sketch of a tent as constructed by the early Hebrews. The square form, the perpendicular walls, the entrance, and all its salient features, are traceable in the permanent structure (*fig.* 4) of a later stage of development. Figure 1 (*pl.* 11) is a sketch of an Assyrian tent of a type which is represented on Assyrian sculptures found at Nineveh, and which is similar to those still in use in the East. This tent is found reproduced in the more advanced Assyrian abode (*pl.* 12, *fig.* 3), where the tent-poles have developed into pillars and the arched roof into a cupola or dome. The patriarchal tents mentioned in the Bible were probably such as are now seen in Arabia, of oblong shape and 8 or 10 feet high in the middle. The ordinary family-tent of the Arabs of modern times is a ridged structure from 20 to 40 feet in length whose covering is a thick felt of goat's-hair. It is divided into two apartments—one for the men, and the other for the women. Figure 2 (*pl.* 11) represents a Turkish tent, whose salient features are traceable in the peculiar minarets of later Saracenic and modern Russian dwellings (*pl.* 13, *fig.* 6). The portable summer tent of the North American Indian tribes never reached a stage of development more advanced than their permanent hut-shelter, or wigwam. Their tents are constructed of a number of poles placed together in conical form, fastened at the top, and covered with skins or the bark of trees (*pl.* 11, *fig.* 6).

Huts.—The first permanent abodes constructed by men were huts, perhaps partially sunk in the ground, the upper part being formed of posts, which were covered with earth and leaves, while the rude walls of the interior were covered with the skins of animals. Domiciles of a similar character are still in use among races in the primitive stage, though their details of construction, and naturally, also, their materials, vary with climatic and local conditions. On Plate 11 we have a number of huts as constructed by different races at similar stages of development in various parts of the globe; the essential features of these dwellings will be found to possess a marked similarity. Figure 3 is a Teutonic hut as constructed by the early Gothic tribes when they ceased their migratory habits and became sedentary. Figure 4 is a hut of scarcely more complicated construction, the habitation of the Slav of a comparatively recent period. Figure 5 represents a domicile inhabited by the populations of Celtic origin whom Cæsar found in the region which he termed Gaul; later historians refer to structures of this kind as composing the villages of these early settlers. Comparing these with the huts of contemporary barbarian races, we find the same characteristics as those before noted. These are traceable in the wigwam of the Pequod Indian (*fig.* 7), in the thatched hut of the South African (*fig.* 11), and in the similar habitation of the sedentary Laplander (*fig.* 9). In this connection may be noted the cliff-dwellings of Southwestern Colorado and the adjacent Territories (*fig.* 8) and the well-advanced and highly-interesting structures of the pueblo Indians, whose communal dwellings (*fig.* 10), consisting of an extensive aggregation of chambers enclosed by walls of sundried bricks or adobes, have some claims to consideration as specimens of architecture.

Egyptian and Soudanese.—The earliest developed architecture of which there are authentic records was that of the Egyptians. The general plan of their structures was naturally determined by climatic conditions, and the details expressed the simplicity of their requirements in the rigid form of the stony materials at hand. The Egyptian required his dwelling not so much as a protection from wind and rain as for a storehouse for his goods and as a shelter for his family. The private dwelling was therefore of very simple construction, the walls being composed merely of lattice-work and of tiles of Nile clay. The separate premises were defined by walled enclosures, the larger part of the space being occupied by an open court, and the various rooms being built against the inner side of the walls. The house was generally of two stories, the lower for sleeping-rooms, while the upper was left open to the sky. Diodorus speaks of four- and five-storied houses, but these were rare exceptions. Figure 1 (*pl.* 12), delineated according to his description, is a sketch of an Egyptian dwelling of the better class. The Soudanese house (*fig.* 2) naturally partakes of the plan of its Egyptian neighbor, and has a marked resemblance to it in its general outlines.

Assyrian.—The dwellings of the Assyrians in the early stage of their development were small dome-shaped brick huts which received light only through the open door, and which were surrounded by a wall enclosing a small court. From the surrounding wall of this court was developed the old Asiatic house, which finally expanded to the proportion of a comfortable dwelling, as seen in Figure 3. Over the chambers which fronted the court there was carried a flat roof, which in favorable seasons was occupied during the day, and which by the wealthy was covered by an awning. Houses of more than one story were comparatively frequent.

Hebrew.—The dwellings of the Hebrews were similar in their construction to those of the Assyrians. They were originally brick huts having a walled court in front, and were used mostly for the storage of goods, and rarely as a shelter. The flat roof of the court was the usual abode of the family. To prevent accidents, the law required the roof to be surrounded by a railing, as seen in the illustration (*fig.* 4.)

Phœnician.—The dwellings of the Phœnicians were similar to those of the Hebrews. In the cities, houses of several stories were common. In the more considerable dwelling (*fig.* 6), the simple upper room became, by the addition of others, a second dwelling, of lighter construction than the ground story, and the flat roof furnished an open place of resort.

Greek.—The early dwelling of the Greeks was simple in the extreme. Traced to its original form, it consists of a court surrounded by a wall and containing a hut. In its more advanced stage (*fig.* 8), and especially in city houses, the ancient wall of the court became the proper wall of the structure. The dwellings were mostly closed toward the outside, the only openings being lofty barred apertures, or peepholes, which afforded only scanty supplies of light.

Etruscan.—The Etruscans, about whom little is known save what is seen in the remains of their huge structures of stone, built their dwellings of that material. It appears that little provision was made for the entrance of light. The door resembles that of the Egyptian and Peruvian dwelling. Figure 7 (*pl.* 12) is a sketch of a late Etruscan dwelling in which the slanting roof had become a marked feature.

Roman.—The primitive Roman dwelling consisted of a single apartment built of latticed work and thatched with straw. The domestic architecture of a later time (*fig.* 9) was entirely different, and, though still bearing traces of the original design, the effect of Greek influence transmitted to the Romans through the Etruscans is generally traceable.

Byzantine.—In the dwellings of the Byzantine period the influence of Greek forms remained paramount. The general plan and arrangement of the dwellings (*fig.* 10), though partaking much of Roman models, was still Greek in character, and more frequently expressive of Oriental than of Western peculiarities.

Aztec.—The dwellings of the poorer classes among the ancient Mexicans were constructed chiefly of reeds and mud. Those of the nobles were built of stone, though they were rarely of more than one story. Figure 1 (*pl.* 13) is a sketch of an Aztec dwelling showing characteristic methods of construction. The walls slanted inward, and the ceilings consisted of a conical arch cut off at the top in a horizontal plane.

Peruvian.—The dwellings of the ancient Peruvians (*fig.* 2), which were also generally of one story, were built of porphyry or granite, or of brick of large size and of an unusual degree of hardness. The walls were of great thickness, though they were seldom more than 12 or 14 feet in height; as they were unprovided with windows, the light was admitted by the doorways, the sides of which (as in the Egyptian dwelling, *pl.* 12, *fig.* 1) approached each other toward the top as seen in the illustration. The roofs were composed of perishable materials, such as wood and straw.

Chinese and Japanese.—The dwelling of the average Chinaman is a simplified form of the somewhat fantastic and highly ornate structures whose characteristic details are so well known. In the country districts, the houses (*pl.* 13, *fig.* 3) are usually of one story with high gable roofs thatched with straw; the walls are constructed of lattice-work more or less closely woven together, according to the latitude and the consequent climatic conditions. Houses of more than two stories are numerous, and are generally arranged with a very low first story, usually devoted to sheltering domestic animals, and with verandas on the level of the upper stories. The houses of the Japanese are generally of one story; they are not high, and are made entirely of wood; they are sometimes plastered on the outside with clay; they are provided with galleries, overhanging roofs, or with broad projections of fine lattice-work.

Hindu.—The original dwellings of the Hindus were constructed more particularly for the purpose of merely furnishing shade, and for a long period they were either airy tents or bamboo huts. In an advanced stage, they consisted of a court surrounded by rooms lighted by the entrance; they had projecting roofs resting on pillars, and an open portico around the courtyard. Houses of more than one story (*pl.* 13, *fig.* 4) consisted above of light balconies, verandas, etc.

Persian.—The dwelling of the Persian (*fig.* 5) was a tent-like structure with a single apartment, and, except in its architectural features, differed little from the Assyrian habitation.

Romanesque.—The dwellings of the Romanesque period, of which Figure 7—a wing of a group of partly-detached houses—is a fair example as regards architectural form, were expressive of Teutonic origin modified by Latin influences. The high gables of the Gothic style were replaced to a greater or less extent by forms more nearly horizontal, and the methods of construction varied in different localities only so far as the local conditions and materials determined. A combination of timber and stone in the structure of the walls was widely prevalent.

Mediæval.—In the Middle Ages, the Gothic methods of construction, depending largely upon timber groining, became widely diffused throughout Europe. In various districts, the original arrangement of the dwelling was modified by foreign influences, Norman, Byzantine, and Roman methods of construction being variously adopted. Figure 8 shows the result of a mixture of the Romanesque and Gothic methods, the lower story being of stone and the upper of timber, the high saddle-roof giving the most definite characteristic to the combination.

Renaissance.—Following the full development of the Gothic styles came the modernized revival of classic forms and of ancient methods of construction. The engrafting of the old styles upon those of later requirements resulted in a commingling of Greek and Gothic forms to which the name of "Renaissance" was given. A characteristic example of this style is shown in Figure 9.

2. MODERN PRIVATE BUILDINGS.

Detached Houses: Dresden Villa.—In erections intended for private dwellings, the most marked differences occur not only from the influences of climate and nationality, but also from the circumstances and taste of the individual proprietor or tenant. The differences arising from national peculiarities are less strikingly exhibited in the more luxurious and elaborate style of buildings than in those of a more inexpensive character. As these elegant abodes seem to mark a sort of dividing-line between domestic architecture and the great edifices prepared for grand memorial or representative public functions, only a single example will be taken (*pl.* 14, *figs.* 1–3). This luxurious private residence, or villa, stands alone, and is intended to be used as the dwelling of one family. The principal rooms—which are intended for reception and domestic purposes—are upon the first story, bed-chambers and spare-rooms are upon the second story, and the kitchen and its appurtenances are in the basement. It must be noted that the villa usually stands at some distance from the street or road, with a garden ground in front to heighten the picturesque effect of the edifice. The chief entrance door is generally in one of the side fronts. The example (*pl.* 14, *fig.* 1)—a villa in the Parkstrasse in Dresden, built by A. Hauschild, architect—exhibits the peculiarities of this style of residence in a handsome and characteristic manner. A wrought-iron railing of artistic design separates the grounds from the street, and the visitor approaches through a gate by a flagstone path leading to the entrance door of the house, before which stands a flight of steps and a lightly built glass-covered *porte-cochère*.

In the house itself the visitor is received first upon the ground floor, *parterre*, or first story (*fig.* 2), in a small entrance hall or platform (*a*), and from this proceeds into an elegant octagonal vestibule (*b*) lighted from above. A door at the left leads to the reception-room (*c*), which communicates with the salon, or parlor (*d*), and through this with the ladies' room (*f*). A passage-way (*g*) contains a small stairway leading both to the basement and to the upper floor; it also makes a connection on the ground floor with the bed-chamber (*f*) and gentlemen's room (*i*), next to which is the small smoking-room (*k*). The room (*m*) in the middle at the rear is the dining-room; the one (*p*) next to it is the pantry, with closet and dumb-waiter. A connecting passage (*o*) unites the vestibule with the stairway to the basement. The front of the salon, which is toward the street, opens upon a gallery, or loggia, for pictures. The side-rooms—that is, the reception-room (*c*) and the ladies' room (*f*)—have bays, also fronting the street. At the rear the dining-room (*m*) opens upon a covered terrace (*n*). The door at the right in the vestibule leads to the stairway (*q*), which connects with the basement and with the upper floor.

In the plan of the upper floor (*fig.* 3), the visitor ascending the stairway arrives at the landing (*a*), which is lighted from above and has a large glazed opening in the floor, to transmit light to the vestibule on the lower floor. The remaining apartments are—room (*b*) for guests, billiard-room (*c*), gallery, or loggia (*d*), living-rooms (*f*). The passages and pantries correspond with those on the floor below; *n* is a stairway to the attic; *r* and *s* are balconies over the bays. In the basement, the kitchen lies directly under the dining-room and the terrace; next comes the servants' room; at the left in front is the bath-room and at the right in front is the janitor's room; at the left in the middle is a mangling-room and under the salon is a cellar. Besides the main building, there are also two side-buildings 58½ feet long and 19½ feet wide (*fig.* 1). In the one at the right are the porter's room, stabling for three horses, coach-house, and harness-room; in the building at the left are the laundry and the conservatory.

German City Residences.—The usual style of city dwelling-house differs from the villa not only in the plainer fittings, but also in having a smaller number of rooms. These dwelling-houses do not often stand alone, being usually built in rows, and are frequently arranged for the accommodation of several families. No universal model can be selected for the German residence, as it is strongly influenced by the marked individuality of the nation; but a very usual type contains a salon, or parlor, large living-room, dining-room, room for the master of the house with a study or library, room for the mistress, a nursery, three bed-rooms, a spare-room with an alcove, wardrobe, kitchen, servants' room, store-room, and two water-closets. In less expensive residences, some of these rooms are omitted. As a rule, a dwelling of this kind is upon a single floor; or the floor may be divided into two dwellings. Each dwelling is usually provided with an entrance or ante-room which may be locked, so that the whole is controlled by this one fastening.

Berlin Dwelling.—An exception to the above will be found in the larger dwellings (*pl.* 14, *figs.* 4–7), in which there is another staircase, necessitating a second entrance. This stairway is seen at *m* in the plan of the ground floor. This house was erected by the government architect Adler in the Dorotheenstrasse in Berlin; it is built in on both sides and has an additional wing. Figure 4 exhibits the handsome façade; Figure 5 shows the ground-plan of the lower floor. The plan of the other story is seen in Figure 6; the wing belonging to Figure 6 is shown in Figure 7. On the lower floor (*fig.* 5) are shown the entry, or hall (*a*); chief stairway (*o*); kitchen (*k*); a small staircase leading to the servants' room above (*l*); sleeping-room (*g*); corridor (*n*); and living- and reception-rooms (*d*, *e*, *f*). The arrangement on the second floor is the same, except that at *f* is arranged a larger salon.

French City Residences.—In French houses of this style, particularly in Paris, there is a separate dwelling on each floor, as in the German model, or occasionally two small ones; but the national customs make them essentially unlike in some of the arrangements. Thus the living-room in the German sense is entirely wanting, its place being partly supplied by the salon, or drawing-room, but chiefly by the more elaborately adorned bed-room. On the other hand, the French house always has a dining-room, which, however, frequently serves as a second ante-room. The dining-room and the salon are also so placed as to be directly accessible from the ante-room proper. In the more elegantly appointed dwellings, pantries, toilet-rooms, etc., are added.

Paris Dwelling-house.—Figures 8 to 11 show the façade and ground-plan of a dwelling-house on the Boulevard Sébastopol, Paris, built by Garnier and Coulon. The ground floor, or lower story (*fig.* 9), is fitted up, as usual, for shops, store-rooms being in the low story which stands immediately above. This second story—intended for offices and store-rooms—is known as the *entre-sol;* the floor immediately above it—being, in fact, the third floor of the house—is known as the first story, being the handsomest flat or dwelling in the building. Each of the other three upper floors contains two smaller dwellings. Figure 11 is the ground-plan of this principal dwelling, or flat. In Figure 9, the plan of the ground floor shows the main stairway (*a*); staircase (*b*) for the *entre-sol*, or second story; stairs (*c*) to basement; stairs (*d*) to the topmost story; opening (*e*) to light the basement; glass plates (*f*) for the same purpose; shop-counters (*g*); cases (*h*); show-windows (*i*); raised seat (*k*); and gas-meter (*m*). Figure 10 shows *a* and *b* as before; store-rooms (*c*, *c*); dépôt (*d*); and room (*e*) for the *concierge*, or janitor. Figure 11 (*pl.* 14) shows the ante-room (*f*); salon (*g*); eating-room (*h*); bed-room (*i*); servants' hall (*j*); kitchen (*k*); and office (*l*). The smaller dwellings in the upper floors have an entrance, eating-room, bedchamber, servants' room, and kitchen, the best houses having a salon also. The façade, shown in Figure 8, will assist in the explanation of this characteristic interior arrangement.

English City Dwelling-houses.—In England the dwelling-houses, even when consisting of several stories, are adapted for the use of one family only; this is accounted for by the national fondness for private family life. As the lots of ground in the large cities, particularly in London, are generally reckoned by the frontage, which is very expensive, this width is usually reduced to a minimum of from 23 to 28 feet. The house extends back into the lot, and the number of stories is increased as seen in Figure 12. To lessen the inconvenience which arises from placing the various necessary rooms upon several stories, these stories are made low, the usual height being from 8 to 11 feet. In front of each residence there is arranged a small depressed space, or area, which is reached from the pavement of the street by a short flight of steps. This open space is intended to afford light and air to the basement. In the latter are the housekeeping- and store-rooms, with the kitchen, and, when needed, a room for the housekeeper. There may also be added a room for the butler. Figures 12 to 18 show the peculiar arrangements of dwellings of this kind.

The basement (*fig.* 13) contains the entry (*a*); housekeeper's room (*b*); wine-cellar (*c*); stairs (*d*); butler's room (*e*); laundry (*f*); kitchen (*g*); yard (*h*); store-room (*i*); servants' room (*k*); cabinet or closets (*l*); the area (*m*) in front of the house; steps (*n*) to same from the street pavement; coal-cellars (*o*), with opening for filling from the pavement; water-closet with reservoir (*p*); stable (*q*); carriage-house (*r*); and stairs (*s*) to a low upper story immediately above. This upper story (*fig.* 15) contains the hay-loft (*a*); water-closet (*b*); coachman's room (*c*); valet's room (*d*); and stairs (*e*). The ground story, or first floor, of the house (*fig.* 14) contains the vestibule (*a*); entry (*b*); hall (*c*); stairs (*d*); dining-room (*e*); library (*f*); room (*g*) for the master of the house; and yard (*h*). The next story above (*fig.* 16), or second story from the pavement, contains the parlors, drawing-rooms, or salons (*a*, *b*); greenhouse (*c*); and stairs (*d*). The upper stories (*fig.* 17) contain the toilet-room (*a*) and bed-rooms (*b*, *c*). Figure 18 exhibits the attic: sleeping-rooms (*a*, *b*, *c*); stairs (*d*); and tank, or reservoir (*e*).

American Dwellings.—In the United States, private residences are exceedingly varied. In the Northern States, the old farmhouse which, with its huge chimney in the centre, its spacious garret, low ceilings, dark winding stairs, and contracted halls, was inherited from English ancestors, has of late years been opened to fresh breezes and wholesome sunshine, and makes a useful typical dwelling, especially as diversified by the revival of the "Queen Anne" styles of decoration, which by their very excesses have cultivated the national taste for individual peculiarities both in form and in color.

The primitive double house was also exceedingly convenient. The wide hall traversing the centre from front to rear opened on one side into a spacious parlor, while on the other side the same space was divided into a sitting-room and a dining-room, with an ample extension behind for kitchen and scullery. A second story was divided into square bed-rooms, and a half-story, or attic, furnished convenient space for storage.

The Log Cabin of the original settler supplied a substantial abode, warm in winter and cool in summer, which, with the addition of rustic porches or long verandas, harmonized well with surrounding forest-scenery. The frame or weather-boarded house which succeeded it, although meagre and angular in its plainer forms, is susceptible of artistic ornamentation and architectural beauty.

Some portions of the country were for a considerable period influenced by an admiration for the severe outlines of Greek architecture, and a large number of handsome private residences were erected upon the type of the Doric and Corinthian temple, making a stately dwelling particularly suited to southern latitudes on account of the high ceilings and lofty porticos. Spanish and Italian architectural ideas have also extensively prevailed in the South, where in many cases all the labors of kitchen and laundry are performed in outside buildings erected for the purpose.

In districts where the effect of heavy snow-storms must be considered, the steep roof is preferred, and there the Dutch and the English types prevail, modified and modernized by the addition of turrets, bow-windows, and decorated façades. The remarkable and rapid substitution of fanciful devices for the rectangular original forms received an impulse from the numerous graceful Swiss-Gothic pavilions built for the Centennial Exhibition of 1876; these are particularly applicable to frame structures, to which the newly-invented machine carvings and mouldings add economic decoration, with the addition of terra-cotta mouldings, tinted tiles, and colored glass. The tide of modern fashion toward seashore- and mountain-resorts for summer sojourning has also given an immense impetus to the erection of decorative cottages and the cheaper forms of architectural design.

American City Houses in their interior arrangements, although English, French, and German styles may be found, have generally been modified to suit the national taste. Thus, in the ordinary three-story city residence (*pl.* 15, *fig.* 2) always designed for the exclusive use of one family, the front door opens upon a vestibule leading into a hall, at the back of which rises an open stairway. On one side, at the front, is a large parlor, behind which are a drawing-room, kitchen, and scullery. Upon the second story the front is given to two bed-rooms, while over the dining-room and the kitchen are a sitting-room, a store-room, and a bath-room. The upper story is devoted to bed-rooms, the servants' room being in the topmost story, to which there is access by separate stairways from the kitchen. Another style prevailing in some districts has on the ground floor a reception-room instead of a parlor, and on the second floor a large drawing-room and ante-chamber, which furnish considerable space for social entertainments, while bed-rooms, dressing-rooms, bath-rooms, etc., are placed on upper stories. It may be remarked that bed-rooms are universally situated at a distance from the kitchen and the dining-room, while elevators are frequently introduced, to lessen the labor incident to the additional number of stories.

In many cities, very luxurious and extensive buildings have recently been erected to supply a demand for residences in "flats;" but, while these are welcomed as possessing certain advantages, the national taste undoubtedly prefers the residence adapted to the single family.

American Suburban Houses.—The diffusion of wealth throughout the country is exhibited by the handsome urban and suburban residences (*pl.* 16, *fig.* 1) built of more expensive materials. These assume numberless variations of the Norman, Gothic, and Swiss models, the architects rivalling one another in producing with astonishing fertility original designs for each succeeding edifice, and in finding in the beautiful native marbles and hard woods abundant supplies for unrivalled luxury and beauty of decoration.

Houses for Workingmen.—In all civilized countries efforts have been made during the last few decades to build special dwellings for laboring-people. Various plans have been adopted on a large scale for erecting such dwellings, to be rented with the expectation that they will gradually be purchased by the occupants. Some of these projects have proved only partially successful because rents have not returned a sufficient interest on the money invested.

The Society for Public Utility, founded in the year 1848 in Berlin, has met with such discouragement. It was organized for the purpose of erecting small dwellings in different parts of Berlin, and upon ground—known as the Bremerhöhe—purchased outside the city. The houses in the latter district were to be so rented that six per cent. was to be returned on the invested capital, four per cent. to be paid to the stockholders and two per cent. credited to the lessees; so that they would become the owners in a period of thirty years. Although the idea has not been fully successful, many persons, through the efforts of the society, have been provided with excellent homes. The plan and elevation of one of these houses intended for two families are given on Plate 14 (*figs.* 19, 20). The dwellings inside are not in flats, but are side by side, and, as each has a separate entrance and stairway, the building is, in fact, a double house. The characteristic feature of the plan is the combination of the entry and the kitchen; so that the kitchen fireplace is directly in the hall. The entrance to the large living- or sitting-room opens on one side from the kitchen, and on the other side are the stairs leading to the bed-rooms on the floor above. Each house has a small garden.

An undertaking of this kind projected at Mülhausen, in Alsatia, in 1853, by Jean Dollfuss and a company, has been perfectly successful. Each family occupies a separate house, the ownership of which is acquired by gradual payments. The houses, built entirely in the French style and under French direction, either stand side by side in rows, so that every two rows touch at the rear, or are combined in groups of four separate houses under one roof upon a square, each fourth of the square constituting one house with garden attached, as in Figure 25 (*pl.* 14). One of these, taken from the group, is presented in Figures 21 to 24. It is 20½ feet long and 18½ feet deep. The general arrangement of the rooms is similar to that already described in the Berlin house. On the first, or ground, floor (*fig.* 22) there is an entry serving also as a kitchen and a living-room. On the second story (*fig.* 23) there are two bed-rooms. The garret (*fig.* 24) is used as a repository, or loft, being purposely built too low for a sleeping-room. Each house has a cellar 6 feet deep. The height of the ceiling in the first and second story is 9 feet in the clear. The privy is built at the side, and is accessible from the outside only; it touches the neighboring one, and has a well in common. The façade (*fig.* 21) is so simple as to require no explanation. Similar houses have been built in Geisenlingen, Würtemberg.

English Workingmen's Houses.—In England, the houses for workingmen have received much attention, and enormous sums have been expended upon their creation; but there have been attempted no plans by which the tenant can become owner. Figures 26 to 28 give the perspective, ground-plan, and sectional view of a house built to contain two dwellings. Each dwelling has two rooms on the ground floor, one intended for a combined living-room and kitchen, and the other for a bed-room. Besides the entry, there are a store-room, or closet, and the stairway leading to the sleeping-rooms on the upper story. The exterior of these houses is picturesque and pleasing both from the peculiar Gothic style of architecture and from the manner in which the two houses are grouped.

American Workingmen's Houses.—The English factory-operative's home is typical of the English workingman's order of being; so, too, with the homes of the French, the German, and the Belgian operatives respectively. In America the operatives of one nationality are not kept long enough to develop a type; and yet, when the operative of this country steps out of the boarding- or the tenement-house, he steps into an individual home whose equal cannot be found in the factory towns of the Old World. The cottage of the American workingman (*pl.* 15, *fig.* 5) usually has a few thousand feet of land about it, and it is so located and constructed as to exhibit a pleasing style of architecture, with an excellent interior arrangement and finish.

In American cities, small and inexpensive residences (*fig.* 1) have received much attention, and the immense cheapening of convenient adjuncts is nowhere seen to greater advantage. In very cheap dwellings a hall, or entry, runs through the house, while a neat parlor is arranged in the front, even when economy of space requires the use of the same apartment for dining-room and kitchen. The small but effective range and sink allow great neatness of finish to the kitchen, and hot water and cold water are supplied to a bath-room in the second story. A cellar furnace for heating the house with warm air, the introduction of gas, the use of dumb-waiters and speaking-tubes, and the excellent and cheap wall-papers render these residences not only neat, but also very convenient.

American Building Associations.—In the United States, the operations of building and loan associations, which have attained great magnitude, have exerted an important influence in facilitating the acquisition of homes by thrifty and industrious persons. It was estimated in 1888 that there were then in this country at least 5000 such bodies, with a membership of 600,000 and an aggregate capital of $750,000,000. Their offices were located in numerous States, in some of which their establishment is of comparatively recent date; but there are a few commonwealths in which unwise or unfavorable legislation, antagonistic judicial decisions, or disastrous results in particular instances have had a tendency to check their growth.

First Organization, Operation, and Membership.—The first American organization of the kind was started in Philadelphia in 1846; since that time many others have been organized in that city. In 1888 their number was estimated at more than 600, with an aggregate capital of $100,000,000, and it was alleged that during a series of years 60,000 persons had been aided in procuring homes. Of the operations of fifty-one associations in Massachusetts, it was recently reported that there was a membership of 20,735, of whom 3797 were borrowers, and that more than 3000 members had been aided by loans in building or in purchasing houses. A similar relation between the number of borrowing and lending members presumably exists in other States, but there have been notable variations in the percentages of members who have endeavored to acquire homes, and in the degree of success or of failure which has attended the operations of different associations.

There are dangers to be encountered as well as benefits to be derived; but of the general system, when properly applied, it has been forcibly said that it is the grandest, simplest, and most successful plan of co-operation ever made practicable in the two hemispheres.

Privileges of Members.—It is optional with members whether they use their share of the money, saved or accumulated, in purchasing dwellings or for other purposes; and in the numerous cases in which funds borrowed from building associations are used to acquire homes, complete freedom of action is usually allowed in the selection of the buildings purchased, provided sufficient security, in combination with other things, is furnished for the loans granted. A large proportion of the members of many of the associations join them with little or no intention of borrowing money or of purchasing buildings. The chief object of this class is to participate in a financial scheme which presumably offers special advantages for the rapid accumulation of small savings by promptly lending them at a high rate of interest to borrowing members, each of whom, in turn, enjoys a share of the profits derived from all other borrowing members, and is also benefited by the privilege of rapidly and steadily diminishing his indebtedness by making numerous small payments. There is considerable variation in the details of the modes of procedure adopted in different cities and States, as well as in the systems pursued by the societies of a given city; and the legislation affecting this subject, as well as the prevailing practice, is occasionally changed.

The Advantages of Building-association Loans to the borrower, and their utility in promoting the purchase of homes, hinge largely on the fact that the basis of a loan may be established by a few small payments, and that indebtedness may be liquidated by having its burden distributed evenly over a large number of weeks or months, under conditions that encourage or necessitate the adoption of economical habits.

Accessory Structures of Dwellings.—Among the accessories of dwelling-houses may be enumerated accommodations for horses, dogs, chickens, and pigeons; also coach-houses, storage for fuel, laundries, green-houses, arbors, verandas, fountains, etc. Some of these contain no features requiring illustration, and but two examples will be given—the green-house (*pl.* 14, *figs.* 29, 30) and the garden-seat (*fig.* 35). The former, which belongs to a private property in Berlin, is remarkable not only for the graceful design of its exterior, but also for its complete furnishing. It contains six divisions, or compartments (ground-plan, *fig.* 30). Three of these lie on a lower level and are covered by an inclined glass roof. The middle part of the upper building has also a glass roof as well as a glazed front. These glazed roofs and walls have skeleton frameworks of iron, not only to increase their strength, but also to obviate obstruction of light. The glazed surfaces are covered with mats, wooden shutters, rolling curtains, and other similar contrivances, to protect the plants from the direct rays of the sun and from the cold of winter. These glazed surfaces should always, if possible, face toward the south. It should be remembered that different varieties of plants require different degrees of heat and demand different compartments (*fig.* 30); among these may be distinguished the cool-house, the hot-house, and the forcing-room. The first, which is used to protect plants in winter, is not warmed artificially, but is sunk about 6½ feet into the earth, to prevent injury from frost. The hot-houses are artificially heated; this is generally done by a low-pressure water-heating apparatus with copper tubing, or by warm air. Finally, the forcing-houses are intended for exotic plants, for ripening vegetables, and for forcing flowers to bloom out of season. The high temperature which is here required is frequently obtained by high-pressure water heating. The chimneys which are inseparable from the heating apparatus are seen in the illustration towering like obelisks at each side of the building. The ornamental seat (*fig.* 35), which belongs to the class of accessory structures erected in the gardens of villas under trees or to command an extended view or landscape, is frequently made of stone, and a trellis of vines is often placed over it, with picturesque effects of statues, vases, and flights of steps.

Interiors of Houses: Hall.—Great variety is also found in the individual rooms and other arrangements of dwelling-houses, a few leading characteristics of which will be seen in the illustrations. Figure 31 (*pl.* 14) shows the design of a hall or entry in a private residence in Berlin. Where the dwelling stands in a row of houses, the hall is preferably placed in the middle or at one end of the façade. As the doors generally stand open, a pleasing vista is arranged toward the garden. When the hall is used for the passage of the house, a wooden flooring is recommended. The height must depend upon that of the first story, but the example shows that great elegance of design is here possible. A notable improvement in the plan of the interior of the better class of American dwellings is the importance given to the entrance-hall (*pl.* 16, *fig.* 3). In the most recent suburban residences the hall is spacious enough to permit of its being used as an ante-chamber or reception-room.

Parlor.—The embellishments of the salon, or parlor, which depend upon the taste of the owner, are generally the handsomest in the house, not only in the adornment of the walls, ceilings, and floors, but also in the furniture, hangings, etc. (*fig.* 2). In the salon of a villa in Potsdam (*pl.* 14, *fig.* 32) the walls have a richly-moulded cornice and are divided into panels. The windows are built out. The illustration shows the large recess enclosed with pilasters and having a straight ceiling; the curtains are double, white lace hanging below, with woollen material above and a lambrequin stretched across the top. The size of such a room is generally from 325 to 525 square feet of area, and from 11½ to 13 feet in the clear for height.

Study.—An example of a handsomely-furnished study is given in Figure 33. Such an apartment frequently contains an area of from 215 to 323 square feet, and is often provided with an accompanying cabinet, which serves as library, sleeping-room, or dressing-room. The study may have shelves for models, statuary, lamps, etc., according to taste, and the general furnishings should be of a heavy and solid character. The study and the library in American houses are usually combined. As with the parlor or drawing-room, the widest latitude is permissible in this apartment for the exhibition of taste in decorative effects.

Bath-rooms.—The bath-room in dwelling-houses is generally very simple in its arrangement, but it is well to paint the walls and ceilings in oil-color, and to have a floor of stone or of tiles. The great variety of elegant decoration allowed in bath-rooms is of much importance, and the use of illuminated tiles admits of any expense or richness of decoration desired. The bath itself may be a zinc tub or a basin set in brick with cement, and lined with white glazed tiles. In German residences it is generally sunk in the floor, and is 5½ feet long in the clear on the bottom, 2 feet wide, and 2¼ feet deep, with pipes for hot and cold water and a drain for waste water. The room and the water are frequently heated by a sort of water stove, unless it is preferred to have a special heater for each purpose (*pl.* 10, *fig.* 21). The bath-room in the best class of American dwellings contains a porcelain-lined bath-tub, foot-bath, washstand, and water-closet (*pl.* 16, *fig.* 4).

Figure 34 (*pl.* 14) is a sumptuous bath-room in the Oriental manner. It is on the ground floor of the palace built by Prince Albert of Prussia near Dresden, and was designed by the late architect Von Diebitsch, celebrated for his work in the Moorish style. The bath-tub is constructed of a greenish-brown marble, and six slender columns support above it a canopy of richly-colored ornamentation. The walls are decorated to resemble tapestry in the same style.

Water-closets.—Figure 36 (*pl.* 14) shows the ordinary fittings for water-closets. The parts are the basin or funnel (*a*), and the soil-pipe (*b*), with the connecting piece belonging to it, or drain (*c*). These may be constructed of various materials, such as well-glazed clay, burnt tile, cement, asphalt, lead, zinc, cast iron, or wood saturated with pitch. The cross-section of the pipes made of these materials is circular in all cases except when wood is employed, and the joints are tightened with cement and oakum. A pipe of this kind may serve for several water-closets situated side by side, or built one above another. The water-trap is set to prevent the foul gases from rising from the pipe, the long end of the pipe being curved upward as at *d* or an immovable pan (*e*) is hung under the opening of the pipe. The English water-closets (vertical section, *fig.* 37) are on the same principle. The arrangement is essentially as follows: The seat (*a*) is provided with a well-fitting lid, and the basin (*b*) is of stoneware, porcelain, or enamelled cast iron, closed below by a copper pan (*c*). This pan, which works on a hinge, is kept in the horizontal position by a counterweight; it is pressed downward in the direction of the dotted line by the weight of the voided matters, and when thus emptied is raised again by the counterpoise. Waste water collecting in the bottom of the pan makes a trap to prevent the ascent of the gases. A second water-trap (*e*) is seen below the iron funnel (*d*). The waste matters are carried to the well through the soil-pipe. The water is brought from an elevated tank to the upper part of the basin by the pipe *f*, and is controlled by the valve *g*. The water, flowing in under strong pressure, strikes against a plate and is forced to spread itself over the basin, which is thus cleansed. The valve can be operated by mechanism or by the hand. The tendency of late has been in the direction of doing away as far as possible with enclosed or boxed-in fixtures of this class. The most improved closets are made, as to body and seal, of a single piece of porcelain standing free in the apartment (*pl.* 15, *fig.* 6).

2. PUBLIC BUILDINGS.

Classification.—Public buildings are devoted either to humane objects in a general sense, such as the fostering and education of children, the care of the poor and the sick, the administration of justice, or to such works of public utility as business intercourse, recreation, refreshment, etc. To the first class belong schools, exhibition buildings, public libraries and reading-rooms, hospitals, court-houses, penitentaries, etc. To the second class may be assigned business exchanges, custom-houses, the fire departments, markets, halls of amusement, washing and bathing establishments, etc. Examples of these buildings are given on the Plates.

Buildings for Education and Training.—With the advance of civilization, buildings devoted to purposes of public utility are rapidly increasing in number, especially those designed for the protection and instruction of youth. For young children who cannot be cared for in the family there are various establishments, such as orphan-asylums, foster-homes, day-nurseries, and kindergartens, where the attention to physical needs is generally combined in some degree with elementary mental training.

Day-Nurseries are usually founded and supported by associations, generally societies of women, and have the special object of receiving infants deprived of the mother's care, or the very young children of women who are compelled to earn their living away from home. This care is usually given without charge, or a small sum is paid by the mother for the shelter of the infant during the hours when she is away at work. Food, entertainment, and instruction are graded to the requirements of the child, and the perils of neglect are thus avoided. In large cities it is found desirable to increase the number of these institutions, and to scatter them among the neighborhoods where they are most needed, as experience indicates that small establishments of this kind can be more thoroughly cared for than those of great extent. Figures 1 and 2 (*pl.* 17) give the exterior and ground-plan of a moderately-sized example of a day-nursery in Frankfort-on-the-Main. On the ground floor there are two large apartments (*a*, *a*); the necessary hall and passage-ways (*b*, *b*); a wardrobe (*c*); a spare-room (*d*); a wash-room (*e*); and a kitchen, privy, and stairs. The upper floor contains living- and sleeping-rooms. The exterior of the building (*fig.* 1) is attractive; garret accommodation is furnished in the arrangement of the gables with steep roof. Such institutions should stand alone, or so that a garden can be attached.

German School-buildings.—In Germany, the buildings or schools devoted exclusively to mental training are usually divided into three classes —the elementary or common schools, the intermediate, and the high schools or universities. The elements of a general education are taught in the elementary schools, which include country, free, district, and grammar schools. In the intermediate grade, embracing the gymnasia and technical schools, the education is carried on farther as a preparation for the academies and universities. In the latter, special departments of purely scientific, technical, and artistic knowledge are provided. Figures 3 and 4 give an example of a village school in Germany; Figures 5 and 6 show a district school; and Figures 7 and 8 a technical school.

Village School and Teacher's Dwelling.—The size and arrangement of the rooms in the village school depend upon the number of scholars, it being considered that a single class must not contain more than one hundred pupils. Thus village schools generally vary from one to four classes, with one or two dwellings for the accommodation of the teachers in charge. The necessity for furnishing the teacher a dwelling in the country schools arises from the fact that the small compensation he receives compels him to forego many of the pleasures of life, and to seek recreation in the domestic circle. The simplest arrangement of this kind for small and poor communities is the single-class house and teacher's dwelling. Figures 3 and 4 (*pl.* 17) give the exterior and ground-plan of one at Neuhofen in Prussia. The edifice, simple on the outside, but built in a suitable style, has a turret for the bell and a small vestibule. At the left of the passage (*b*) is the large class-room (*a*), intended to accommodate one hundred pupils; it contains an elevated desk for the teacher. At the right of the passage is the teacher's family- or living-room (*c*); in the rear is a smaller room (*d*) that can be used as a study. The kitchen is at *f*, store-room at *g*, and a small connecting passage or hall at *h*. The bed-rooms are in the upper story, and the privies for the school and the dwelling are on the outside of the house.

The District Schools of Germany occupy an intermediate position between the free and the grammar schools, and are intended for the children of persons of limited means. The chief difference between them and the free schools is that in the district school a moderate sum is charged for tuition, the arrangements are more like those of the grammar schools, and they are in many cases identical.

Dresden District School.—Figure 5 is an exterior view of a district or parish school, and Figure 6 is the ground-plan. This school is in the Pillnitzer Strasse in Dresden, and was built (1867–1868) by the City Board of Works. By a peculiar arrangement, the staircases and privies are made double, so as to divide the building into a boys' and girls' department, while all that is common to both schools is in the middle of the building. The four gable-ends are constructed without windows, so that the light may enter the school-room from but one direction. The building contains accommodations for eight classes of boys and eight classes of girls, six being in each of the wings and four in the front part of the ground floor and second story of the main building. The third story of the latter is occupied by the dwelling of the principal, while the rear part of the main building on the ground floor is reserved for rooms for the janitor, and on the second floor for business-rooms and a store-room for school supplies. The arrangement for the ventilation of the class-rooms, which is connected with a hot-air heating apparatus, is very effective.

Chemnitz Technical School.—The technical schools are modern institutions restricted rather to the arts and sciences than to the professional or liberal branches, and are intended as a preparation for the high schools, Polytechnic, and universities. The example in Figures 7 and 8 was built (1868–1869) on the Reitbahn Strasse in Chemnitz by the City Board of Works. Figure 8 shows the perspective of the exterior, and Figure 7 the ground-plan of the second story. The latter has in the middle of the building a grand central hall (*a*) extending upward through both stories, being distinguished on the exterior by large windows and rich ornamentation. At the rear, besides a grand double-headed stairway, there is a light-well (*g*). On the right is a large room (*b*) for drawing, on the left the privies (*h*), a connecting passage (*f*), a lock-up, or safe (*e*), and at the rear face of the building the museums of natural history (*d*, *d*). Finally, in the wings are eight lecture-rooms (*c*, *c*) with corridors.

The ground floor of the building contains in the middle of the front an open porch and a spacious vestibule, adjacent to which, on the right, are the dwelling and office of the janitor. On the left is the physical department, with the laboratory and the recitation-rooms for the classes in physics, and also other class-rooms. In the right wing, next to the janitor's apartments, are business-rooms for the teachers, a despatching-room, and at the extreme right two more class-rooms like those upon the second story. In the rear of the main building there are additional water-closets, and under the museums of the second floor extend chemical class-rooms, a small laboratory, and a museum. On the third story, at the rear, are three library-rooms; a librarian's room stands over the safe, or lock-up, and the other rooms correspond with those beneath. In the right wing there is a large room for drawing, which is provided with cabinets at the side for teachers and for drawing-utensils. In the basement, besides cellars and storing-places for fuel, there are four heating chambers, in which Kelling's heaters are used, combined with a system of ventilation.

American School-buildings.—The vast requirements of the free-school system of the United States have led to the use of a great variety of buildings, and in different sections they may be seen, from the long, low shed with a row of single panes of glass set into the side walls without sashes, through all grades of architectural device, to the ornate edifices resembling Norman castles and Gothic cathedrals.

Girls' Normal School.—The type of a substantial and capacious building may be found in the Girls' Normal School, Philadelphia. The ground-plan is a simple parallelogram with two halls, each 16 feet wide, crossing the middle in both directions, with wide stairways at each end. Upon each side of the longest hall are six class-rooms, 35 by 20 feet, the four corner ones being slightly larger. Upon the second floor a similar hall runs through the building, the entire space upon one side being devoted to an assembly-room, 107 by 66 feet, containing at one side a raised platform 54 by 15 feet. A hall at right angles with the former divides the remaining space in the middle, having on each side cloak-rooms 5 by 13.6 feet, a pupils' dressing-room, and a teachers' room 26 by 12 feet. Behind these smaller apartments are class-rooms, three on each side. The third story contains twelve class-rooms, repeating the plan of the first floor. The building was erected at a cost of one hundred and seventy-five thousand dollars.

The usual plan for arranging school-houses is substantially as follows: A large assembly-room in a central position is surrounded by class-rooms, with wide halls and stairways; for convenience and despatch, the cloak-rooms are arranged beside the stairs. Heating is by hot air or steam, and in the newer buildings much attention is paid to ventilation and plumbing. Dwellings for teachers and janitors are never included in the school-houses, and even in colleges and academies, where students are lodged and boarded, separate buildings are usually provided for the purposes of tuition, apart from dormitories and eating-rooms.

Leipsic Gymnasium.—Besides institutions devoted to mental training, those devoted to physical education deserve special attention. The ground-plan (*pl.* 17, *fig.* 9) shows a gymnastic institute built at Leipsic, at the expense of the city, from plans by Giese. The building consists of a two-storied front building and the gymnasium hall itself, which is surrounded by wide galleries. The letters on the ground-plan of the first floor refer as follows: *A*, porch; *B*, dressing-room; *C*, teachers' room; *D*, writing-room; *E*, record-room; *F*, passage; *G*, privies; *H*, the part of the hall under the galleries; *J*, open hall. In the front building are the main stairs with a double head, and at the rear another stairway (*o*), leading to the gallery, with a room for storing apparatus beneath the stair. The gymnastic appliances are a frame (*d*) for hanging-ladders, swinging-bars, and see-saws; a frame (*e*) for climbing, with sixteen perpendicular and eight diagonal bars, four climbing- and two rack-poles, four climbing- and four stepping-ladders, two climbing-ropes, swinging-rings, and trapeze; parallel bars (*g*); horizontal bars (*h*); swinging- and climbing-ropes (*i*); boxes for storing apparatus (*k*); leaping-bars (*l*); horses (*m*); cupboards (*n*) for weights, dumb-bells, etc.; gas-meter (*o*); stove (*a*); benches (*b*); and washstands (*c*). The floor of the hall is of clay covered with a layer of tan. The gallery, supported by iron columns, contains vaulting-tables, bars, and racing-tracks. The hall is lighted by two rows of arched windows, twenty-eight in all, and also by a skylight in the roof. On the second floor of the front building are a fencing-hall and rooms for the director, teachers, and janitor.

Hospital and Penal Institutions.—Buildings for the temporary lodging of the sick and those for the detention of criminals present many features in common, notwithstanding the different purposes for which they are designed. In both, it is equally necessary that the plan should provide a number of rooms under convenient supervision, with sufficient accommodations for officials and attendants, together with provision for household service and supply. Hospitals can be divided into those intended for mental and physical diseases.

Schwetz Insane Asylum.—Figures 10 and 11 give the ground-plan and exterior of a modern establishment of the first kind—the insane asylum at Schwetz, constructed mainly from the design of Building-inspector Steudener of Halle. Indispensable conditions in appropriate arrangements of a hospital for the insane are completely fulfilled in the example by the complete separation of the sexes, and convenient intercommunication throughout all parts of the establishment. Other points of essential importance are an airy situation for the building, gardens for recreation, separation of sleeping- and sitting-rooms, and a convenient arrangement which brings the business offices of the institution into ready connection with the dwellings of the officials. All these primary requisites are well met in this example. The asylum lies outside the city, on a plateau elevated above the Vistula River, and commands a fine view of the surrounding country—a matter in itself of great importance in the treatment of mental maladies. It is surrounded by a wall and is divided into two departments—one for men, and the other for women. All that is in common to both departments is situated in the centre.

On the main front, in the centre (*pl.* 17, *fig.* 10), is the business department (*a*), with a yard and accessory buildings. Farther back are the domestic offices (*d*), with steam-engine and laundry (*c*). At the extreme rear is the department for violent cases, divided into a side for men, and one for women (*i*, *k*). The front wings (*c*, *c*) contain the wards for the men on the left, and for the women on the right. The wings at the back, divided from the front by a wall, are devoted to the incurable patients. Each of these four divisions, or wings, borders on two gardens, of which, in each case, the inner garden is devoted to the excitable patients and the outer one to the quiet patients. The department for women, although less crowded, is of the same size as that for men, for the reason that experience has shown the necessity of separating and isolating female patients to a greater extent than is requisite for men, and also that the individual occupations pursued by women require special rooms. All the buildings communicate by covered halls. The entire water supply of the institution is provided by a steam-engine, which drives the machinery for the laundry and furnishes steam for heating the baths and bath-rooms.

The central building for business offices is three stories in height and contains rooms for the porter, with offices for general regulation and registration, etc., and accommodations for the director, clergyman, unmarried physician, superintendent, inspector, accountant, and clerk. In the basement are the porter's room, laundry, etc. Besides the rooms for the patients, each wing contains a dining-room, reading-room, and amusement-room furnished with piano, billiard-table, etc. The department for violent cases contains isolated cells with barred windows high above the floor. The building for domestic service (*d*) contains on the ground floor the large kitchen of the establishment, with steam cooking apparatus and the necessary adjoining rooms, closets, and store-rooms, with apartments for the cook and the female servants. The boiler-house is at *c*, and immediately behind it stands the laundry, which is two-storied; the upper floor being a drying-room. Baths for men and women are in the wings of the building (*d*), and in it also is the chapel for religious services.

American Insane Asylums.—In the United States, public attention has been much attracted to the care of the insane, and large expenditures of money and of benevolent exertions have been bestowed upon the provisions for their safekeeping and mental improvement.

The State Hospital for the Insane at Norristown, Pennsylvania, demonstrates the fact that cheap accommodation can be provided for the indigent insane by avoiding the usual expensive administration buildings, and that such an institution need not necessarily require an imposing structure under one roof. This has been accomplished by the erection of eight separate ward-buildings, with boiler-house and laundry, kitchen, chapel, administration building, porter's lodge, stables, and outbuildings. The group of buildings has a front of 1481 feet and a depth of 913 feet. The general dimensions of the separate ward-buildings are 277 feet in length by 90 feet in depth. Each ward-building consists of a basement, used for steam-heating ducts and workshops, and two main stories, each containing two wards and giving four wards to each building. Each ward is complete in itself, with separate rooms, dormitory, dining-room, bath-room, etc. The wards are ventilated by stacks with steam coils at the base for creating the draught that draws the impure air from the wards. The entire institution is well supplied with water and gas, and is heated by steam from the central boiler-house. The buildings stand upon an elevated plateau, the main front facing south-east, and are surrounded by extensive grounds. Connected with the hospital and owned by the State are about three hundred acres of land, portions of which are devoted to truck-gardens, whose cultivation furnishes wholesome employment to some of the patients. The total expenditure for the construction of the buildings has been $599,850. The institution was prepared for about 1100 inmates, and the cost of construction is estimated at $545 per bed. The supply and administration buildings are adequate for a larger number of patients, and a further increase of capacity could be provided at a much smaller cost per bed.

German Hospital at Berlin.—The ground-plan and elevation (*pl.* 17, *figs.* 15, 16) present the hospital of the Augusta Union at Berlin—an institution for the treatment of general diseases. It is on a small scale and is built on the barrack system, an entirely modern idea offering special advantages in its method of construction for a brisk change of air and thorough ventilation. In this example a part of the hospital (*c*, *c*) is arranged as a tent lazaretto, in which patients can have the fullest benefits of the fresh air. Small special chambers (*d*, *d*) are also prepared for individual patients afflicted with severe or infectious maladies. Each barrack, built of frame, with weatherboarding, and provided with narrow encircling galleries, contains fourteen beds in two rows; it also contains, besides, a room (*e*) for female attendants, a bath (*g*), and two water-closets. In the middle building there are also rooms for female attendants, closets and bath, and a tea-kitchen. In the rear of this building is a room for religious service, and over it, on the second floor, a meeting-room for the managers. The domestic rooms, kitchens, etc., are in the basement.

American Hospitals.—In the United States, during the Civil War, much attention was necessarily concentrated upon the equipment of temporary military hospitals, and the marked improvements then introduced were extensively adopted in Germany during the Franco-German War, and have been since used in many of the European hospitals. A surgical pavilion-ward built upon this principle may be thus described: The ward, 30 by 88 feet, having a capacity for twenty-eight beds, is placed in a building of one story upon a rectangular ground-plan of 38 by 143 feet. The entrance is into a hall 6 feet wide; on one side of this hall are an operating-room 11½ by 16 feet and a nurses' room 11½ by 14 feet, with linen-closet attached. On the other side of the hall are a diet-kitchen, lavatories, baths, and water-closets. At the back of the ward is a sitting-room 30 by 16 feet. The windows are glazed double, and the building is heated by indirect steam radiation, the impure air being drawn off through registers under each bed into a ventilating-shaft. The foundations are stone, surmounted by brick walls, with an air space in the brickwork. To exclude moisture, the surface of the ground beneath is covered with asphalt, and the floor is lifted 5 feet from the ground, the space being open for the circulation of air through arched openings in the walls along the sides of the building. The ward has also ridge ventilation. The hospital of the University of Pennsylvania, at Philadelphia (*pl.* 18, *fig.* 1), furnishes a fair example of this order of public institutions in the United States. It was erected in 1874 upon a plot of ground donated by the city on the condition that fifty free beds should be maintained for the sick poor.

The Municipal Prison at Cologne (*pl.* 17, *figs.* 12–14) is a good example of a penal institution. Preliminary provision is here made for arrested persons and those serving out the penalties for minor offences; also medical supervision of prostitution and temporary lodging for prisoners in transit. The accommodation is for about fifty men and twenty women. The basement is in two sections. The first is reached by the main staircase from the women's prison and yard attached to the housekeeping-rooms; it contains tea-kitchen, bath-room, laundry, scullery, and cellars for food and fuel. The service in the kitchen is chiefly supplied by the female prisoners. The other section of the basement is reached from the men's courtyard, and contains a large workroom, bath, and cellar for fuel. Storerooms—reached only from the front court—are also in the basement, under charge of the supervisors. The main entrance to the ground floor (plan, *fig.* 12) is in the front court. The receiving-room (*a*) communicates with a fireproof room, and the rooms (*b*, *b*) for the male and female supervisors are so arranged that the yards and windows of the institution can be overlooked. The ground floor, at the back, contains two rooms (*c*, *c*) for four persons subject to protracted confinement, one apartment (*g*) for five invalids of a certain class, an apartment (*d*) for five arrested persons, one solitary cell, one sick-room (*e*) for cutaneous diseases, and one (*i*) for treatment of internal troubles.

On the second floor (*fig.* 13, plan of the front part) is the room (*h*) for prayers, divided by a board partition into two parts—one for the men, and one for the women—physicians' consultation- and examining-rooms (*i*, *i*), which form an ante-chamber to the chapel; also a part of the men's prison. The third story contains three spare-rooms and the remainder of the men's prison. The latter, on the second and third stories, contains eight rooms for four persons who may be subjected to a protracted period of detention, two rooms for five persons arrested who are to remain a short time, four solitary cells, and two sick-rooms. Four courts, or yards, are attached to the building—one in front, one each for male and female departments, and one for domestic use. The exterior (*pl.* 17, *fig.* 14) has a forbidding appearance, being built in the mediæval style of architecture.

American Reformatory Institutions.—As a penal institution requiring peculiar provisions may be cited the State Industrial Reformatory at Huntingdon, Pa. The main wall encloses a space 680 feet square, containing 10.6 acres. At the centre of the front, but outside the wall, is the administration building, which includes the entrance-gate. Upon entering through this building into the enclosure, the visitor passes directly into the centre building of the institution, which contains, on the ground floor, a large open apartment with a bathing-pool. Above this, upon the second floor, is a guard-room commanding a view of all the wards, and above this, upon the third floor, is the chapel, or assembly-room. Four wards radiate from this central building, two of them parallel with the enclosing wall, the other two striking off at an obtuse angle. These wards contain three tiers of cells, each 8 by 9 feet, with a height of 8⅓ feet. The cells are 744 in number. In the open space between the ends of the wards are three-storied school-buildings, one for each ward. Behind the central building, and connected with it by a two-story corridor, is a building whose ground floor contains eating-rooms, and whose second story sleeping-rooms for employés. In the rear are buildings for kitchen, laundry, etc., and farther in the extreme rear workshops for the employment and instruction of the inmates. The foundations of all the structures are stone surmounted by brick walls. The floors are artificial stone resting upon brick arches. The cells—used only as sleeping-rooms—are brick with cement flooring and iron-grating doors. The stairways and galleries are iron. The edifice is strictly fireproof. Steam generated in a boiler-house behind the kitchen warms the institution, and an engine furnishes power for the workshops. The institute being intended as a reformatory for youthful offenders, graduation through the schools is provided for merit, and industry, progress, and good behavior in the workshops are rewarded by privileges.

Public-houses and Hotels are fitted up in a great variety of styles, to suit the diversified requirements of their customers and guests. Those of the most expensive kind resemble in so many respects the handsomest private residences that no special description is necessary.

The Emigrant-house in Bremerhaven (*figs.* 17–19) is a lodging-house of a peculiar style, as it is fitted for the temporary needs of persons awaiting the departure of emigrant-vessels. This useful public institution, erected (1849–1850) by the members of the Bremen Exchange, is intended to shelter and board two thousand persons. The main building, whose lowest floor is shown in the ground-plan in Figure 17, contains rooms arranged as follows: In the middle of the front are the entrance (*a*); porter's rooms (*b*, *b*); corridors (*c*, *c*); landings with stairs (*d*, *d*) to basement and upper stories. In left wing are the dining-room (*e*), with a room (*f*) attached; landing and passage to chief steward's room (*g*), with door opening to yard; sailors' eating-rooms (*h*, *h*); small rooms (*i*, *i*) for storage; entrances (*k*, *k*) to church; room (*m*) for altar-vessels; sacristy (*l*); and church (*n*). In the right wing are the offices (*o*, *o*, *o*); corridor (*p*); inspector's dwelling (*q*, *q*); dwellings (*r*, *r*) for pastor and manager; nurses' room (*s*); landing with water reservoir and door to yard (*t*); female nurses' room (*u*); corridor (*v*); privies (*w*); sick-rooms (*x*, *x*, *x*); and landing and stairs (*y*, *y*) to cellar. On one side of the basement is the large kitchen, with adjoining rooms and steam-cooking apparatus; on the other side are large rooms where the baggage of the emigrants is deposited. The lodging-rooms proper are on the upper floors, as follows: nine dormitories, with a wash-room attached to each. The interior arrangement of one of these dormitories is seen in Figure 19. Besides a large open space and portions provided with large tables and benches, there are special compartments separated from one another by vertical partitions and provided with berths, in order to serve as sleeping-apartments for families or for companies travelling together. An attendant is stationed in each lodging-room. The exterior of the building, seen in perspective in Figure 18 (*pl.* 17) is quite effective, and the style is very suitable to the purpose. Behind the main building, and parallel with it, is another building for store-rooms.

Eating Establishments in which simple and nourishing food is furnished at a small charge are an outcome of the advanced ideas of modern times, like many of the buildings already described. The ground-plan of an institution of this kind started in Leipsic at the instance of the City Union for Relief is given in Figure 20. It can furnish meals for two thousand persons daily. The rooms are as follows: *A*, corridor for the public, with entrance (*a*); *b*, cash-window; *c*, window for receiving food; *B*, a small landing with exit on the street; *C*, the women's eating-room; *D*, cashier's room; *E*, kitchen, with kettle (*d*) for vegetables; *e*, serving-room for meats; *f*, chopping-block for meat; *g*, tables; *h*, range with steam apparatus and six kettles; *i*, kettle for cleaning peas, etc., of husks; *F*, store-room; *G*, eating-room for men, with entrance from street; *H*, staircase; *J*, landing; *K*, boiler-room, with (*r*) steam generator for cooking-kettles; *L*, engine-room, with pump for filling boiler; *M*, yard for domestic uses.

American Eating-houses.—Establishments for a similar purpose have increased rapidly in the United States during recent years, but are rarely built for the express purpose, as they are presumed to be of temporary utility, and any convenient building is used for the emergency. The Sunday breakfast offered to the indigent in many places is an instance of a similar service, while cheap meals at cost-price have been faithfully furnished by institutions that have been known under the pleasing designations of the "Holly Tree Inn" and "Boffin's Bower." There are also many benevolent institutions which furnish soup and coffee at a nominal price as a relief to the suffering poor or as a substitute for intoxicants. The organized benevolence of the present day supports such institutions in almost every large city or town.

Continental Custom-houses.—Buildings are erected at certain places in Europe, as on the boundary of a city, for the collection of duties, excise, or toll. Figures 1 and 2 (*pl.* 19) give the perspective and ground-plan of one of these, which stands at the north end of the Tête d'Or Park, at Lyons, France. It is decorated with perforated wood and colored tiles, and has a picturesque effect harmonizing with the surrounding landscape. The ground floor (*pl.* 19, *fig.* 2) includes a passage, two receiving offices, and two sleeping-rooms for the night service. The second floor contains the dwelling of the collector or receiver.

American Custom-houses.—Up to a comparatively recent period, the most expensive buildings erected or owned by the Federal Government, aside from those located in Washington, were custom-houses. The cost of construction, exclusive of cost of site and alterations and repairs, of the New Orleans custom-house was $4,221,824.40, and corresponding outlays for the custom-houses of other cities included the following: Boston, $884,346.76; Charleston, South Carolina, $2,696,592.34; Chicago (custom-house and sub-treasury), $4,529,709.24.

Post-offices, United States Court-houses, etc.—During recent years liberal Congressional appropriations have been made for the erection of post-offices, and buildings intended to provide accommodations for them, as well as for United States courts and various classes of national officials. The work of constructing buildings of this class has been progressing for a number of years, and hundreds of fine structures, representing nearly all known styles of architecture and varying greatly in size and capacity, have been erected. The sums spent for them probably exceed any other governmental outlay for architectural purposes during a similar period, and the cost of some of the most expensive of the new structures is exceptionally large, the reported cost of the construction of the New York court-house and post-office being $8,549,832.63, and corresponding outlays in Philadelphia exceeding $6,000,000.

Court-houses present differences according to the organization and purposes of the tribunals for which they are designed. Figure 3 gives the plan of the second floor of the general court-house at Bonn, as follows: *a*, audience-hall of the court of Common Pleas and of the court of Correctional Appeals; *b*, ante-room; *c*, library; *d*, conference-rooms; *e*, president's room; *f*, ante-room; *g*, room for secretary and criminal registration; *h*, counsels' room; *i*, jury-room; *k*, *l*, rooms for state or prosecuting attorneys; *m*, for the chief state counsel; *n*, ante-room; *o*, secretary's room; *p*, recorder's room; *q*, witnesses' room; *r*, assize-hall; *s*, judges' consultation-room; *t*, room for defendants. On the ground floor are the examining-rooms for the two courts, with a direct communication to the prison in the rear. The central part of the edifice has a third story with a skylight, in which are a secretary's room and the archive-rooms, the latter having stone floors supported by vaulting, and vaulted ceilings with iron beams, to render them fireproof. In the basement are rooms for janitors and for the storage of fuel. In the United States, the court-houses erected by different cities and counties represent many styles of architecture and variations in amount of expenditure and completeness of accommodations.

Berlin Exchange.—Figure 4 gives the ground-plan and Figure 5 the interior perspective of the main hall of the Exchange or Bourse at Berlin, built in 1860–1864 by the merchants of that city from plans by Privy Counsellor Hitzig, and under his direction. The building has a handsome façade adorned with columns and statues, and the interior is treated in a rich, tasteful, and substantial manner. The ground floor, shown in the plan, has an open portico (*a*) in front, leading into the large vestibule (*b*); in the rear of this, the centre of the edifice is occupied by the Exchange (*c*, *c*), extending through two stories in height, with arcades on columns on the second story, and divided on the first floor into Stock and Produce Exchanges by a similar arrangement of columns and arcades. Niches are formed on the lower floor by pilasters, and over these, in the second story, are narrow galleries bordered by the arcades. All the columns in the hall, one hundred and twenty-eight in number, are monoliths of polished granite. The light is supplied by the windows and by passages at the rear; the building is warmed by large heaters in the basement. The ceiling, in the form of a flattened arch, is highly original in design, and produces a fine effect. The iron ceiling-ribs are strongly outlined, and above them sickle-shaped iron girders, invisible to the eye, span the hall at distances corresponding with the columns. Iron beams are arranged between the former, and the squares so formed are filled in with highly-ornamental plaster bays. The flooring is of oak planks enclosed in a marble framing.

At the left hand, near the vestibule, are the wardrobe (*d*) and closets (*e*), and in the corner a porter's room (*f*), reached through a special small passage (*g*). A stairway leading to the upper floor and gallery is also accessible from the same passage. Farther back, in the left wing, are the telegraph-offices (*h*–*m*). At the rear are a back stairway lighted by a well (*n*), the bulletin-rooms, and two other apartments (*p*, *q*). In the rear is the large open exchange (*r*) for summer use, adorned with colonnades and fountains. To the right of it are the brokers' room (*s*), a passage (*t*), and the Liquor Exchange (*u*). The right wing on the front is not so important, owing to its shape; it contains only a few cabinets (*v*), stairs, and another wardrobe (*w*), with closets (*x*). Finally, on the right of the wide vestibule are the main stairs to the upper floor and rooms for the porter's use (*y*, *z*). In the second floor, directly over the vestibule, is a session-room; on the left are the cashier's office and registry; at the right, rooms for committees; and in front is the library. The left wing and rear of the building to the right are occupied by dwellings.

Arcades: Galleria Vittorio Emanuele.—Among the erections intended for business interchange should be mentioned those collections of shops which in some cities are called "arcades." Those intended for the finer classes of merchandise are frequently styled "bazaars," while those of a gallery-like construction, forming cross-connections between two streets and covered with glass, are known as "glass-passages" or "galleries." Almost all important cities in Europe have now these elegant structures. One of the newest and largest is the Galleria Vittorio Emanuele, in Milan (*pl.* 19, *fig.* 7); it connects the Piazza del Duomo with the Scala. This gallery, built (1865–1867) by the architect Mengoni, has a cruciform ground-plan, and over the centre is an octagonal cupola decorated in its upper part with four large fresco paintings. The side-walls, which are richly and tastefully finished, have double pilasters with corresponding semicircular iron roof-girders. The roof over the galleries, as well as that over the cupola, is of glass; so that the elegant shops on both sides of the passage are well lighted by day, and the entire edifice is profusely illuminated at night.

Public Libraries are situated either in buildings used for other purposes or in edifices built expressly for use as public libraries. The chief room of the library is the reading-hall, open to general use, and provided, as a rule, with accessory apartments, but sometimes serving only for the storing of volumes, being fitted with suitable cases upon the walls.

Imperial Library, Paris.—Figure 6 shows a reading-room of imposing dimensions. It belongs to the public library of Paris, formerly known as the Imperial, the most important in Europe. It was opened for use in 1865 in one of the new wing-additions to the Hôtel Mazarin of the old library. The bold construction and the elegant gilded finishing render the interior very imposing. The vaults of the domes, which are light—or, at least, made to appear so by skilful coloring—are furnished with skylights, and are supported on slender iron pillars, making at once an elegant and a fireproof ceiling. Around the walls in the spaces between the pilasters are bookcases in three rows, whose two upper ranges are reached by light iron galleries. In the hall are large tables for the use of the readers. The rear of this immense hall is semicircular, and here the attendants have a place of resort behind a railing. The library is heated by a hot-water system.

The New Library of Congress, at Washington, D. C., will, when completed, be the largest library-building in the United States. The plans, which have been substantially decided upon, contemplate a building in the Italian Renaissance style of architecture. The exterior walls will be of stone and the interior will be constructed of iron and concrete, to render the building as thoroughly fireproof as possible. The inside finish will be generally plain except in the reading-room of the rotunda and in the main stair-hall, or vestibule, which will be suitably enriched with marble, iron, and stucco. If erected according to the plans now awaiting approval, the building will accommodate, at once, 1,500,000 volumes, and ultimately (as the proposed extensions are added) 3,500,000 volumes. The elevation of this projected building is shown in Figure 2 (*pl.* 18). Its dimensions will be 450 feet long by 330 feet wide.

Establishments for Fire-engines and Houses for Washing and Bathing are intended for the useful application of water previously brought into them. Of buildings intended for service in the extinguishment of fires, only those for the storing of implements, or pumping-houses, range in this class: they need no special illustration, and only one example will be given (the force-pump, *pl.* 19, *figs.* 8, 9).

Paris Laundry.—Figure 10 (*pl.* 19) gives the interior perspective of a public laundry in Rue de Sèvres, Faubourg Saint-Germain, Paris. The main hall here shown is lighted from above and has two tanks, or troughs, running the whole length of the hall. These troughs are supplied from the river Seine by a forcing apparatus. Parallel to them are tables for soaping the linen, which accommodate one hundred and fifty washerwomen and are furnished with a like number of spigots for use when required. The waste water is carried away in pipes beneath the flagstone floor. Next the wash-room is the bleaching department, worked by steam. The articles washed, first arranged in nets and numbered, are placed in special vats, and the bleaching fluid, or lye, is driven through them by means of steam. The wash is then dried, by rotating drying-machines, in from seven to ten minutes' time.

Bathing, Drinking, and Washing Establishment.—Figures 11 and 12 show a bathing-and-drinking establishment combined with one for washing, as built in Münster by Hauptner. The washing department is in the rear of the building, while the baths and the drinking fountains occupy the extensive front. The plan of the ground floor (*fig.* 11) shows the symmetrical arrangement and the excellent architectural treatment of the design, while the façade (*fig.* 12), notwithstanding its simplicity, can be recommended for its effective and artistic appearance. The ground-plan (*fig.* 11) shows, *a*, the fountain for drinking; *b*, buffet; *c*, *c*, stairs to second story; *d*, front entry; *e*, *e*, waiting-rooms; *f*, *f*, the ladies' baths; *g*, *g*, family bath; *h*, *h*, gentlemen's baths; *i*, *i*, rooms for male and female attendants; *k*, *k*, sulphur baths; *l*, *l*, privies; *m*, kitchen; *n*, *n*, light-wells; *o*, boiler-house; *p*, engine; *q*, *q*, steam-bath ante-rooms; *r*, sweating-room; *s*, steam-bath; *t*, *t*, wash-house; *u*, ironing- and mangling-room; *v*, *v*, drying-machinery; *w*, Russian bath; *x*, exit-pipe; and *y*, *z*, warm- and cold-water pipes. Over the waiting-rooms and the passage (*d*) are parlors in the second story, and over the room *w* is a large tank.

Roman and River Baths.—Figures 13 to 19 give examples of establishments where water is used exclusively for bathing. Figures 13 to 15 show a Roman bath, and Figures 16 to 19 a river bath. The numerous Roman baths constructed in recent years are arranged upon the model of the ancient Roman bath, the chief peculiarity being that the bather spends a certain time in a room heated to a high temperature by hot air before entering the bath, which is lukewarm or cold; other processes, such as massage, or kneading the body, douching, rubbing with soap, etc., are added.

The Roman Bathing-house at Hamburg (*figs.* 13–15) is arranged as follows: From the entrance parlor (*fig.* 13), which is elegantly fitted and furnished with divans, the bather proceeds into the cool room, or frigidarium (*fig.* 15), adorned with aquariums, tables with flowers, etc. On the sides of the frigidarium are sixteen small compartments which can be closed by means of curtains on the side next the central passage. Each of these compartments contains a bedstead with covers, wash-stand, chair, bath-linen, slippers, etc. After disrobing in this apartment, he enters the warm room, or tepidarium (*pl.* 19, *fig.* 14), an apartment with a high-vaulted ceiling, lighted from above, with a temperature of 122° Fahr. Into this room, the floor of which is tiled, a constant current of hot air is driven from below, the respired air escaping at the top through ventilators. After remaining in this apartment about twenty minutes, the bather enters another compartment, several degrees warmer, the sweating-room or sudatorium (*fig.* 14), seen through the open door. His stay is here limited to about ten minutes, during which he lies upon a bench and is manipulated by an attendant. He next passes to the lavatorium, or wash-room, where lukewarm water is poured over him repeatedly; he is then subjected to a douche, or shower-bath, at first lukewarm and gradually chilled, and is finally rubbed off. Wrapped in a bathing-robe, he returns to the frigidarium to rest upon the bed in the compartment first allotted to him as a dressing-room.

The River Bath at Magdeburg, on the Elbe (*figs.* 16–19), is remarkable for its admirable appointments as well as for its favorable position in mid-stream (*fig.* 17). As in almost all baths of this kind, there are separate divisions for men and women, and a swimming-basin. The entire structure is supported upon a raft, or float, anchored by chains, while it is free to rise and fall with the water of the river. The arrangement shown in the ground-plan (*fig.* 16) is as follows: The approach from the shore is made over a convenient bridge, which leads into the front garden-plat (*a*), with the main entrance (*b*) and buffet (*c*) immediately behind. On the left is the men's waiting-room (*c*), and that for the women is on the right (*d*). A small kitchen is at *f* and a store-room at *g;* along the sides, galleries for women (*i*) and for men (*h*) lead to the controller's offices (*k*, *l*). From them the bather either enters one of the compartment baths—of which there are fourteen for men (*q*, *q*) and the same number for women (*r*, *r*)—or the swimming-bath (*p*). The latter has dressing-rooms at the side and a douche (*o*) behind, with rooms for attendants at *m* and *n*. At the extreme rear is a place for drying bathing-suits, etc. Figures 18 and 19 show the construction of the swimming-basin and private baths. Both have plank flooring and lattice-work partitions below the surface of the water, to permit its free flow. The swimming-basin is not covered, but is surrounded by a walk, which separates it from the dressing-rooms. The compartment baths have roofs which can be raised to admit light and air.

Mineral-water Stands.—Structures for the accommodation of those who drink the natural mineral waters of medicinal springs at watering-places often have bathing-rooms attached. These arrangements are of ancient origin, but the small fountains or spas intended for carbonic-acid water or soda water are of entirely modern design. Figures 20 to 23 illustrate two examples of the latter. A mineral-water stand in Berlin is seen in perspective (*fig.* 21) and in ground-plan (*fig.* 20). It consists of two divisions connected by a door; the division in front, which is furnished with a counter, is open, while the one behind is for storage and the temporary shelter of the person in charge. The building is of wood and has a pleasing appearance. A similar edifice in Paris is seen in perspective in Figure 23 and in ground-plan in Figure 22 (*pl.* 19). It is graceful and light in its style of finish and adornment.

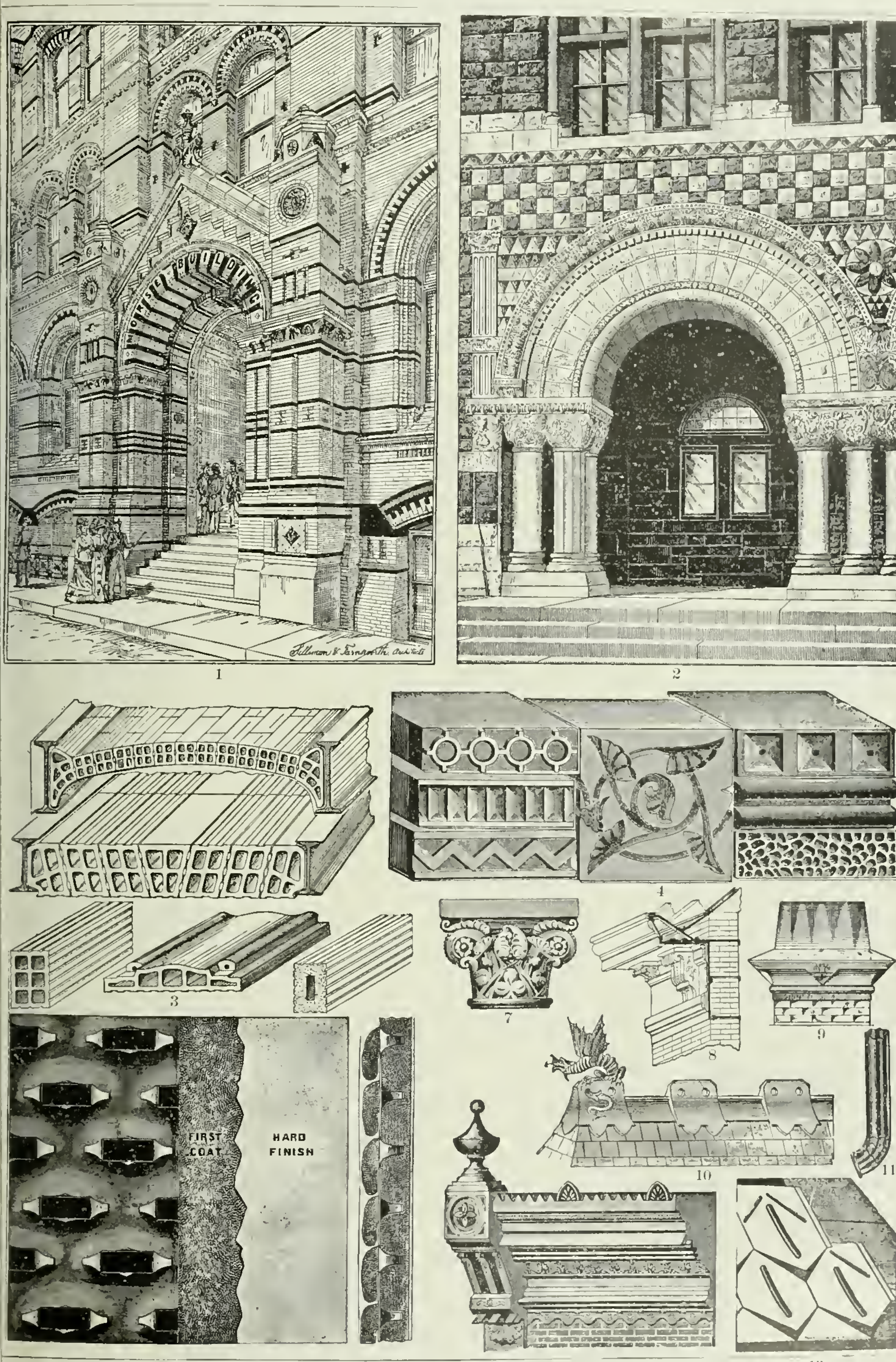
Market-, Exhibition-, and Festival-halls, which may be classed among the modern structures devoted to useful purposes, are generally characterized by their light construction, usually of wood and iron, and also by their consisting frequently of one lofty apartment with galleries; these buildings are rarely divided into stories. Market-halls and exhibition-halls have been described (p. 65) as being partly constructed of iron, especially the Crystal Palace at Sydenham and the World's Exhibition at New York in 1853. Halls for festivals resemble those devoted to exhibitions, for the reason that they also are generally erected for temporary purposes; in the former, however, as more permanent, iron is used to a greater extent, while halls for festivals are generally made exclusively of wood.

Dresden Festival-hall.—Halls intended for the Schützen-, Turner-, and Sänger-fests are frequently quite elaborate in decoration and fanciful in design. An imposing example of this kind was constructed at Dresden in 1865 from plans by Giese and E. Müller, architects, for the first German Sängerbundesfestes in that city. Figure 24 presents the exterior of this building. The hall, built on a pile foundation, and mainly of wood, was intended to accommodate twelve thousand singers and an audience of fifteen thousand. On the four corners were high towers, and between them six smaller towers. The hall proper consisted of a stage for the choristers and of the auditorium. Encircling the hall was a gallery for the display of the banners of the several societies. Large windows over the galleries, eighty-six in number, were filled with transparent variegated paper colored in oil instead of with glass; the handsome allegorical figures upon these had a very good effect. All the rooms were open to the public, and were artistically decorated with bunting, flags, painted shields, etc. The towers were divided into stories, and gave ample space for committee-rooms, police, mail and telegraph offices, sick-rooms, retiring-rooms, beer-buffets, etc. Under the great stage was reserved a place for the fire department.

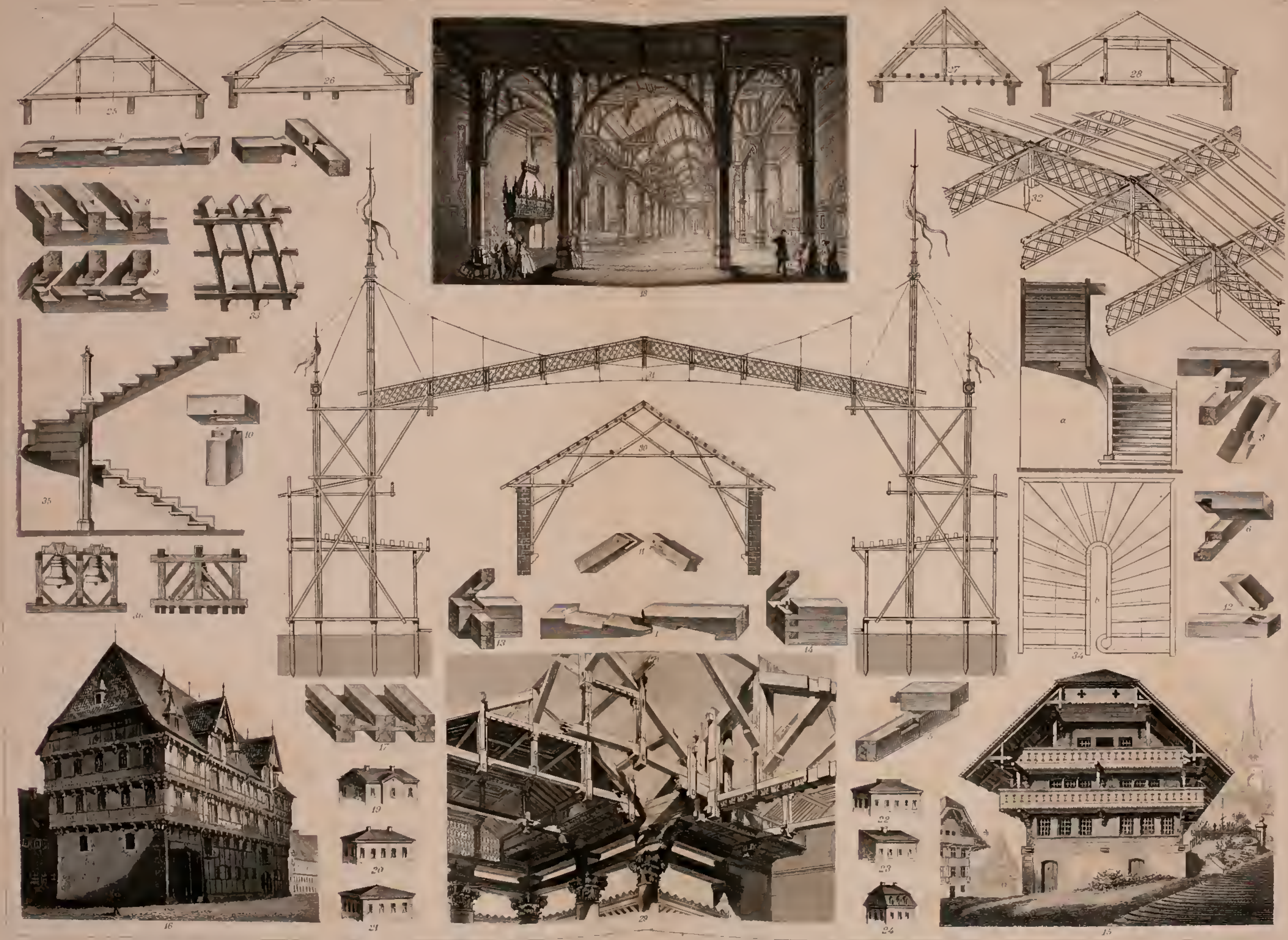
United States Centennial-exhibition Buildings.—The main building of the Centennial Exhibition in 1876 was an immense structure (*pl.* 18, *fig.* 3). It was in the form of a parallelogram, extending east and west 1880 feet in length, and north and south 464 feet in width. The larger part of the structure was one story high, the main cornice on the outside being 45 feet above the ground and the interior height 70 feet. At the centre of the longer sides were projections 416 feet long, and at the centre of the short sides projections 216 feet long. The projections contained the main entrances and the central façades, 90 feet in height. On the corners of the building were towers 75 feet high. The roof over the central part for 184 feet square was elevated above the surrounding portion, with towers at each corner rising to a height of 120 feet. The ground-plan showed a nave, or central avenue, 120 feet wide and 1832 feet long. On either side of this nave were avenues of the same length and 100 feet in width. Between the nave and the side avenues were aisles 48 feet in width, and on the outer sides aisles 24 feet in width. The foundations consisted of piers of masonry and the superstructure of wrought-iron columns supporting iron roof-trusses, the columns being composed of rolled channel-bars with plates riveted to the flanges. The columns in the building were uniformly 24 feet apart. Of the six hundred and seventy-two columns employed, the shortest was 23 feet and the longest 125 feet, the aggregate weight being 2,200,000 pounds. The sides of the building, to the height of 7 feet from the ground, were finished in brickwork in panels between the columns. Above was glazed sash, parts of which were movable, for ventilation. The exterior of the structure was ornamented with galvanized iron octagonal turrets extending from the ground to above the roof, to support flagstaffs. Louvre ventilators were placed over the nave and each of the avenues. Balconies, or galleries, from which the interior could be viewed, were provided in the four central towers. The building was erected as a temporary structure, the columns and trusses being so designed that they could be readily taken down and rebuilt upon another site. There were used in the construction four miles of pipe, 7,000,000 feet of lumber, and 8,500,000 pounds of iron. The structure cost $1,600,000.

Agricultural Hall, a building in the Centennial Exhibition, was specially remarkable for the originality of its design. The structure consisted of a long nave crossed by three transepts, all composed of Howe truss arches of Gothic form. The four courts between the nave and the transepts, as well as the four spaces at the corners of the structure, having the nave and the transepts for two of their sides, were roofed, and formed spaces for exhibits. The nave ran north and south, and was 820 feet long, 125 feet wide, with a height of 75 feet from the ground at the top of the arch. The remaining three transepts ran east and west, one at each end of the building 540 feet long and 30 feet wide, and one in the centre 540 feet long and 60 feet wide. The building was thus divided into sections, each of which had aisles 197 feet long and 13 feet wide extending through it and communicating with the avenues and passage-ways. The entire structure covered ten and a quarter acres of ground, and the arrangement was much admired for its novelty and grace, the general appearance resembling that of a great cathedral.

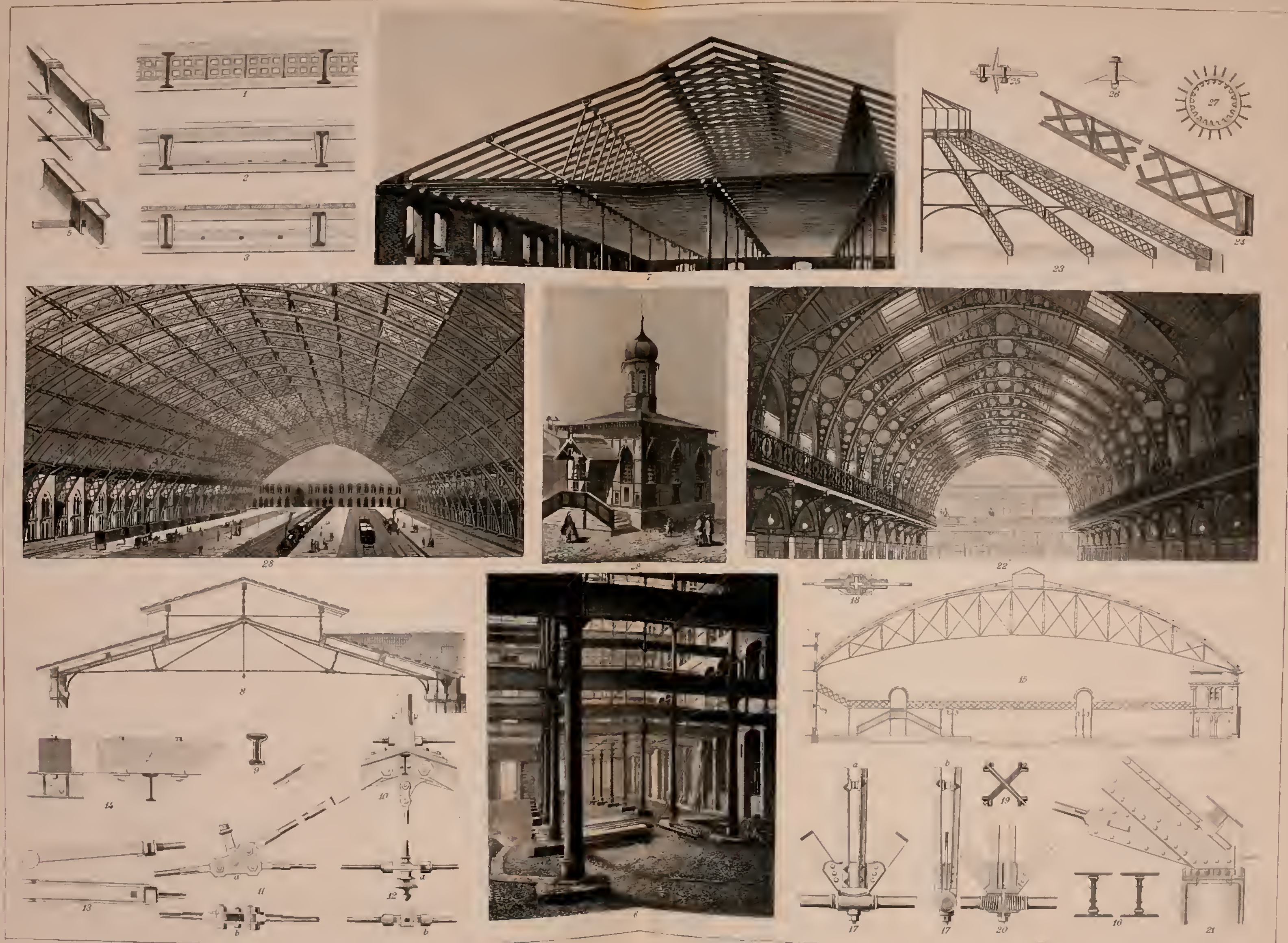
1–12. Bonding and Masonry: 1. Block bond, 2. Cross bond, 3, 4. Hollow brick walls. 5–7. Various forms of masonry or ashlar bond. 8. Gothic or Polish bond in masonry. 9. Rustic stone-work. 10. Concrete walling. 11. Stone framework: Greek temple at Fano. 12. Ancient Grecian arch. 13–16. Vaulting: 13. Groined vault. 14. Lierne vault: Grand hall (Remters) of the Marienburg castle. 15. Hanging dome: St. Mark's Church, Venice. 16. Fan or funnel vault (top view). 17–23. Stone Stairways: 17. Straight-line stairs: Munich Library. 18. Broken-line stairs and hall of a dwelling in Berlin. 19. Double-headed stairs. 20. Winding stairs of the Early Renaissance, from a French castle. 21. Perron of the Hôtel de Ville, Paris. 22, 23. Brick stairs.



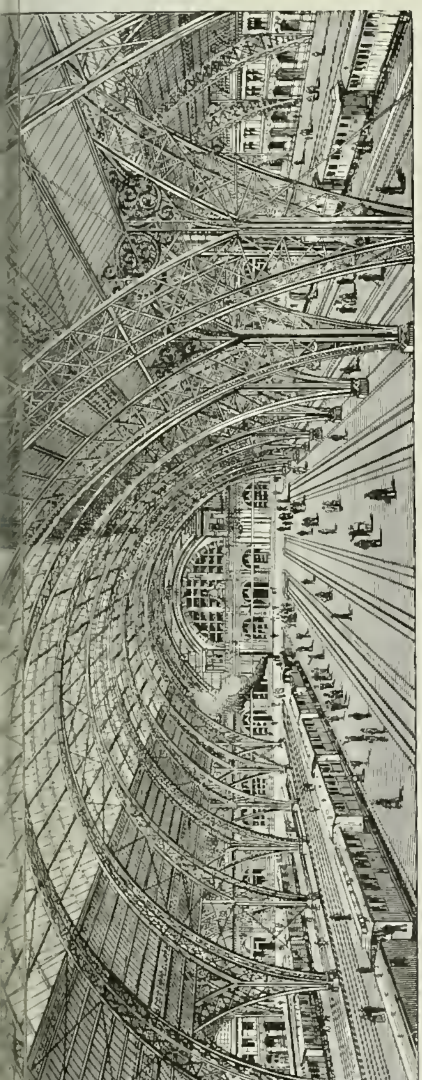
1. Enamelled and moulded brick-work: Morse Building, New York City. 2. Ashlar work: Austin Hall, Harvard University. 3. Hollow bricks. 4. Peerless moulded ornamental bricks. 5. Plan, 6. Section, of fireproof metallic lathing. 7. Metallic column-capital. 8. Metallic cornice-fastening. 9. Metallic chimney-cap. 10. Metallic roof-crest. 11. Corrugated rain-pipe. 12. Metallic cornice. 13. Metallic roof-tiling.



1–14. JOINERY: 1. Oblique scarfing. 2. Right-angle square-halving. 3. Acute-angle square-halving. 4 Dovetail mortise. 5. Shouldered-tenon mortise. 6. Dovetail corner joint. 7a–c. Side-, middle-, and cross-cogging. 8, 9. End cogging. 10. Mortise and tenon. 11 Slit tenon. 12. Oblique tusk tenon. 13. Corner-joint of log walling with projecting ends. 14. Corner joint of log walling, with flush ends 15 Swiss dwelling: Sigristen house, Marbach. 16. Alte Wage (Custom-house) at Brunswick. 17. Floor-beams with intermediate false flooring 18. Great hall of the Gurzernich at Cologne. 19–24 FORMS OF ROOFS: 19. Saddle-roof with side gable, 20. Hipped saddle-roof, 21 Pavilion roof, 22 Flat-top roof, 23. Lean-to roof, 24 Mansard roof. 25–33. ROOF CONSTRUCTION: 25. Double standing-post roof, 26. Oblique-post roof, 27. Single suspension-truss roof, 28. Double suspension-truss roof, 29. Combination suspension-truss roof: Roman basilica at Fano, 30. Roof-truss without joists, 31. Lattice-truss roof: Sängerhalle at Dresden, 32. Details of Figure 31, 33. Curved roof-truss of plank rafters: Riding-school at Wiesbaden. 34a, b. Housed-in winding stairs 35. Geometrical stairs. 36. Bell frame in Saint Thomas's Church at Leipsic.



1–6. IRON CEILINGS: 1–3. Cross sections of iron-girder ceilings as constructed in Paris. 4, 5. Perspective section of iron girders with supporting rods, used in the ceiling construction of Figures 2 and 3. 6. Perspective of iroo girders and columns designed for a vaulted ceiling: Joint-stock Spinning-works at Chemnitz. 7–28. IRON ROOF CONSTRUCTION: 7. Saddle-roof with attic framing: Joint-stock Spinning-works at Chemnitz. 8. Suspension truss-frame roof: Market-hall at Nancy (Polonceau). 9–14. Details (of Figure 8) of truss framing. 15. Bowstring truss-frame roof: Central Railway station, Birmingham, England. 16–21. Details (of Figure 15) of bowstring truss-frame. 22. Arch rib roof: Diana Bath at Vienna (Etzel). 23. Straight lattice-girder roof: Otto Circus at Berlin. 24–27. Details (of Figure 23) of lattice-girder roof. 28. Curved lattice-girder roof: St. Pancras Station, London (W. H. Barlow). 29. Iron church at Dünaburg (Von Struve).



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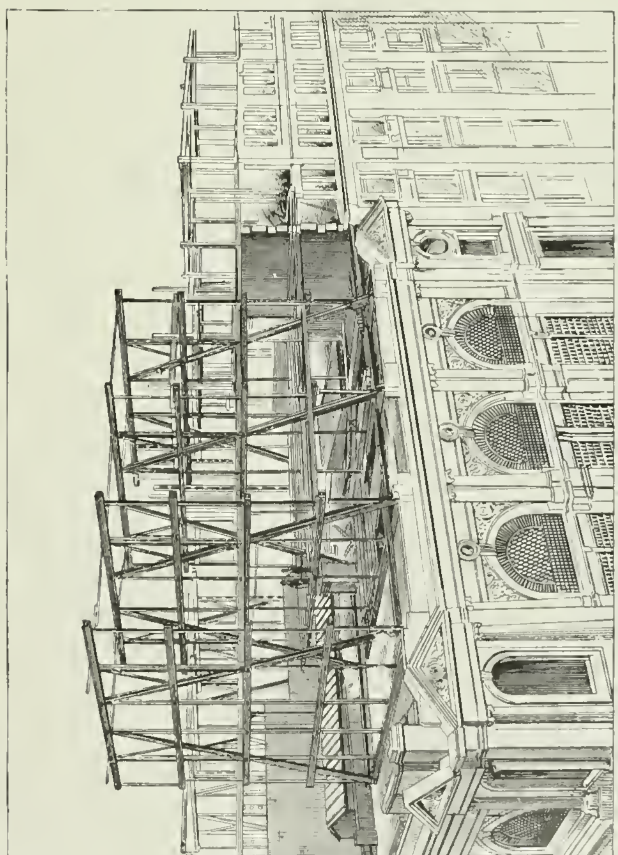

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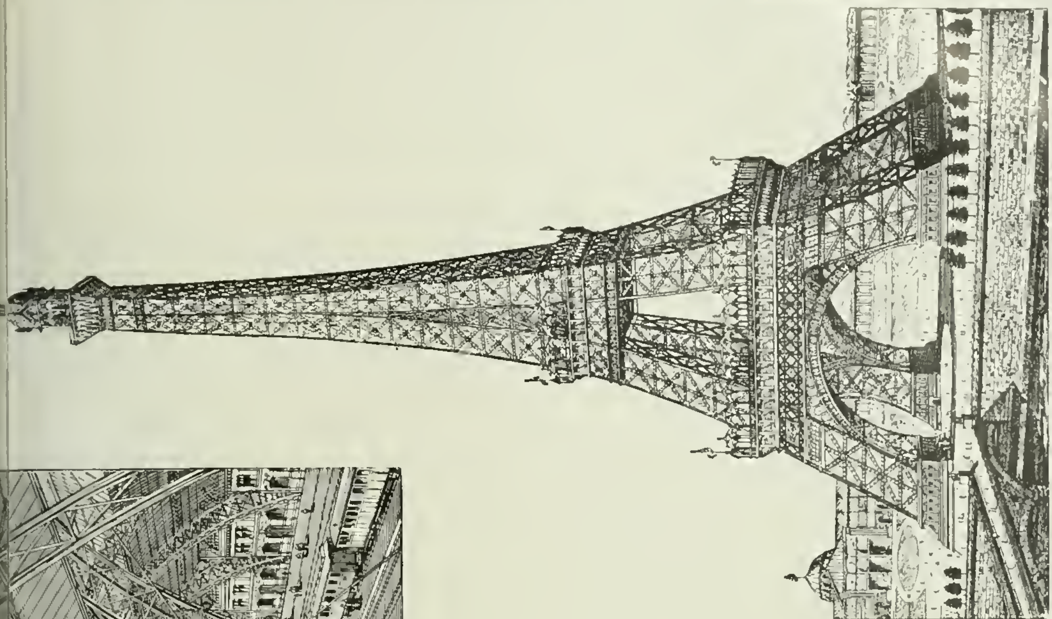

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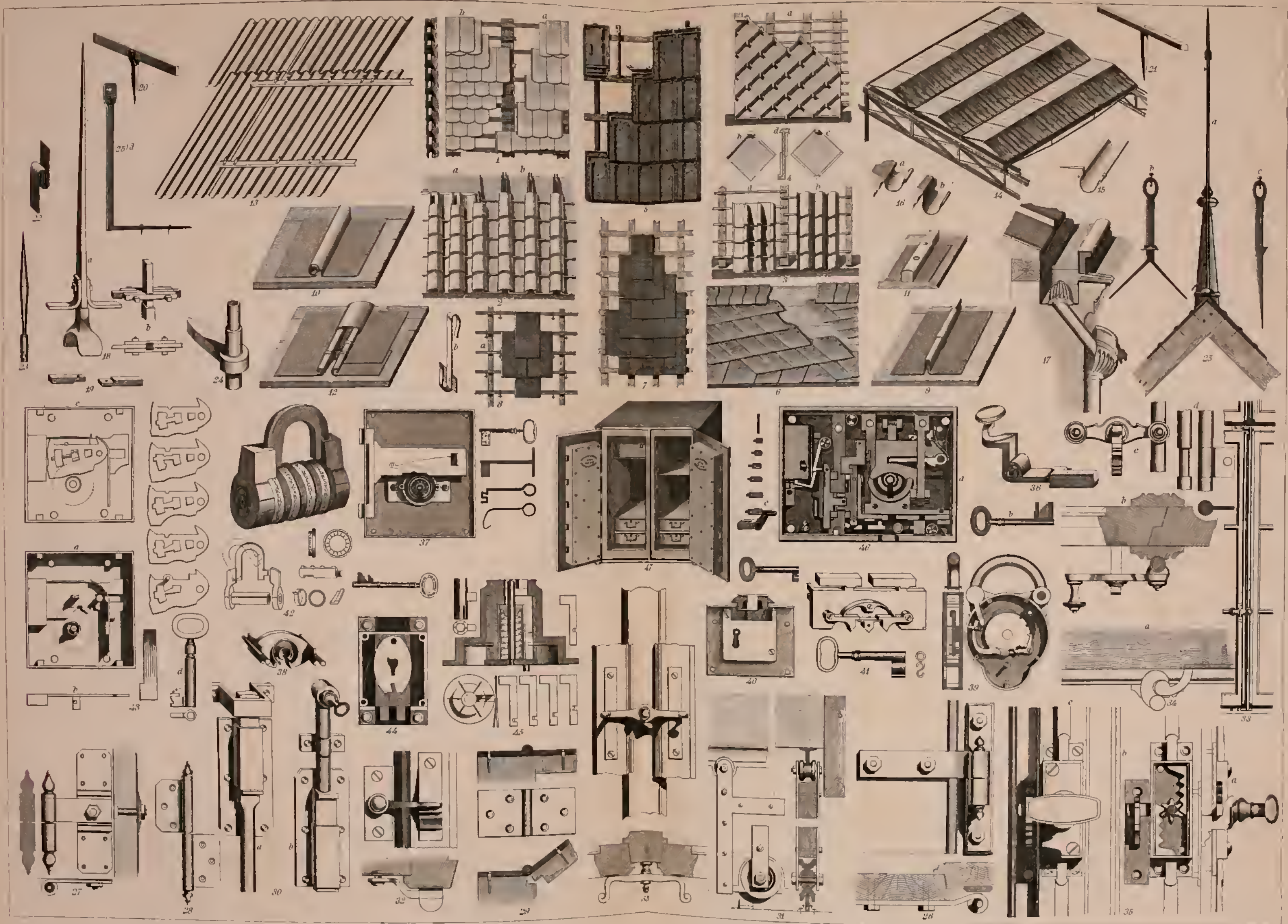
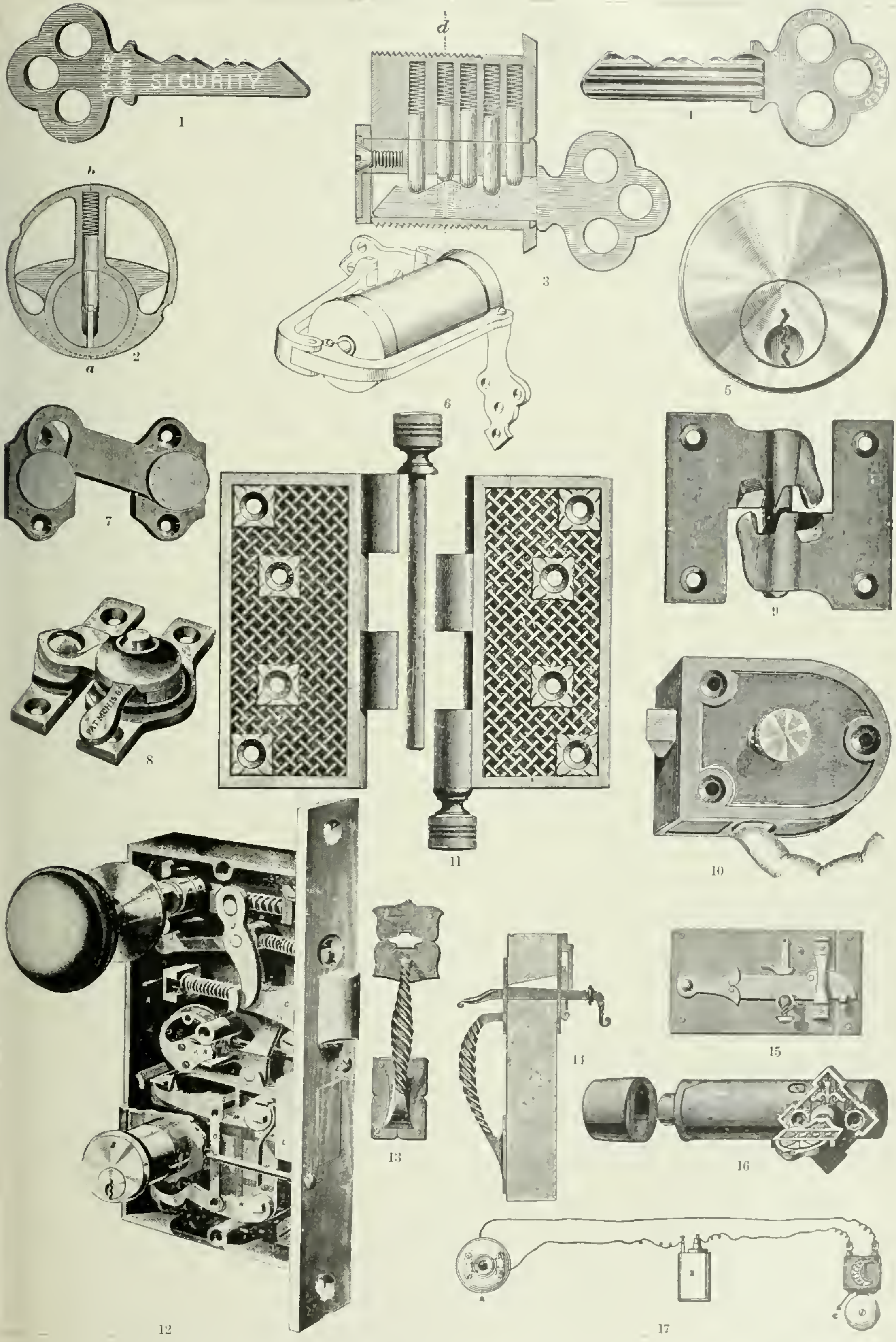
1. Train-hall of the new Central Railway-station (*pl.* 29, *fig.* 1), at Frankfort-on-the-Main. 2. Truss construction of the Drexel Building, Philadelphia (Wilson Brothers & Co.). 3. Eiffel Tower, Paris (Gustave Eiffel).

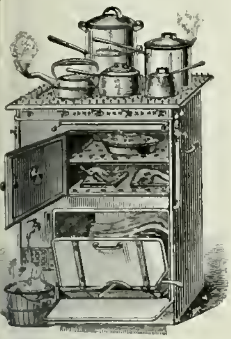
1. Cast-iron pavilion in the Botanical Garden at Munich (Bergmann). 2. Cast-iron Friedrich-August Tower, on the Löbauer Berg in Saxony. 3. Bronzed cast-iron standpipe on the Place de Breteul, Paris, of the artesian well at Grenelle. 4. Section of the dome of the Capitol at Washington, D. C (Thomas U. Walter). 5. Cross-sectional perspective of the Market-hall at Lyons, France (Desjardins). 6, 7. Constructive details of Figure 5. 8. Perspective, 9, Interior, of the New York Industrial Exhibition building (1853). 10. Perspective, 11. Interior, of the Crystal Palace (1852–1854) at Sydenham, London (Joseph Paxton). 12. Interior perspective of an upper gallery, 13, 14. Constructive details, of the Crystal Palace (*figs.* 10, 11). 15. Cast-iron winding stairway.



1–14 ROOF COVERINGS: 1a. Single-tile roofing 1b. Double-tile roofing. 2a. Gutter-tile roofing. 2b, 3a. Combination gutter-tile roofing. 3b Pantile roofing 4a–d. Courtois's square rebated-tile roofing. 5. Oblong rebated-tile roofing. 6. German diagonal slate roofing 7. English double-slate roofing on wooden laths, 8a English double-slate roofing on iron laths. 8b. Hook for fastening slates in iron laths. 9 Standing seam, 10. Rolled joint, 11 Lath joint, 12. Rolled joint with cap, for metallic roofing. 13. Corrugated-iron roofing. 14 Fluted-glass roofing; section of the Crystal Palace, London. 15. Hanging roof-gutter with fastening. 16a Section of the upper end, 16b. Section of the lower end, of a hanging roof-gutter. 17. Box roof-gutter, with rain-pipe connection. 18–25. Details of fastenings and terminations of lightning conductors. 26–46. DOOR AND WINDOW FITTINGS: 26. Strap hinge (elevation and plan). 27. Cross-tailed hinge (elevation, section, and plan). 28. Butt hinge. 29. Charnier band, or pivot hinge (elevation and plan). 30a, b. Vertical-sliding door bolt. 31 Sliding-door rollers (elevation and cross-section). 32. Half, or single, turn-buckle (elevation and plan). 33. Double turn-buckle (elevation and plan). 34a–d. Details of the espagnolett, or French lever, fastening. 35a–c. Details of the bascule fastening. 36 Night-latch. 37. French lock and keys 38. Key ward. 39 Padlock in section. 40. Desk lock and key. 41. Chest lock and key. 42. Letter lock (elevation and details). 43. Chubb lock and key. 44 Price lock and key. 45. Bramah's combination lock (details). 46a–c. Newell's permutation lock and key (details). 47. Fireproof safe.



1–5. Yale lock: 1. Original key. 2. Transverse section, 3. Longitudinal section, of the escutcheon of a lock. 4. Corrugated key. 5. Front view of an escutcheon. 6. Norton door check and spring. 7. Window-blind catch. 8. Sash fastener. 9. Self-fastening shutter hinge. 10. Secret spring latch. 11. Loose pin butt. 12. Yale standard front door lock. 13–15. Details of thumb-latch. 16. Concealed bolt. 17. Electric call-bell.



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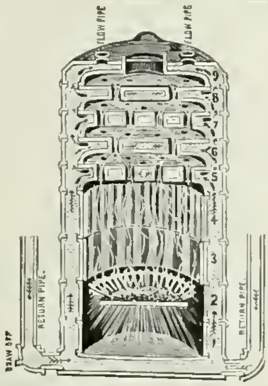

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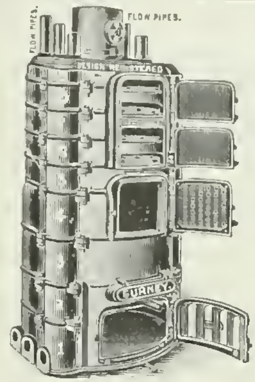

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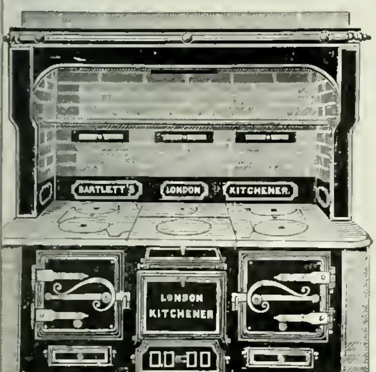

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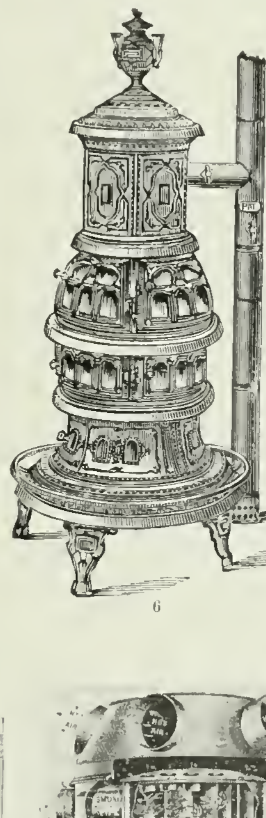

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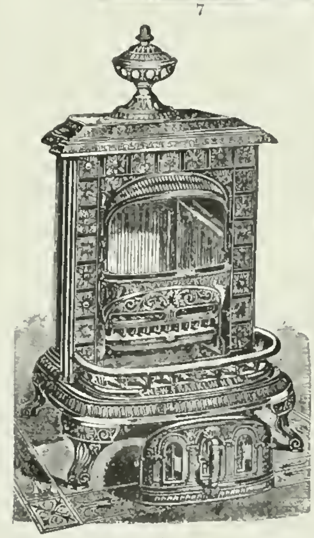

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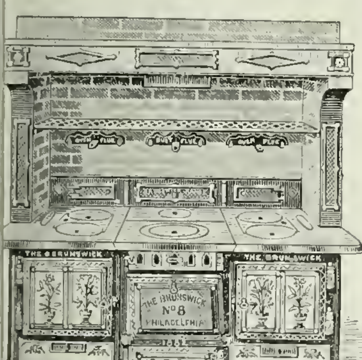

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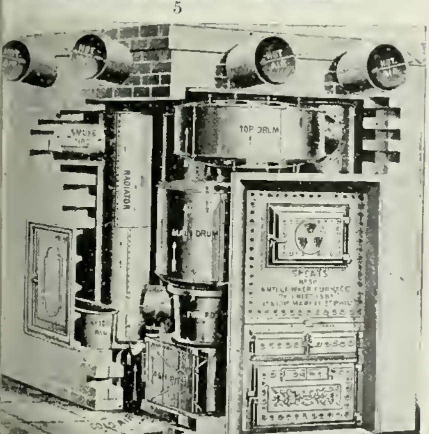

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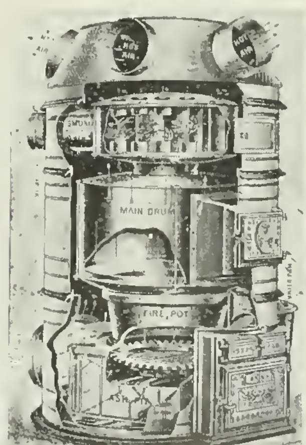

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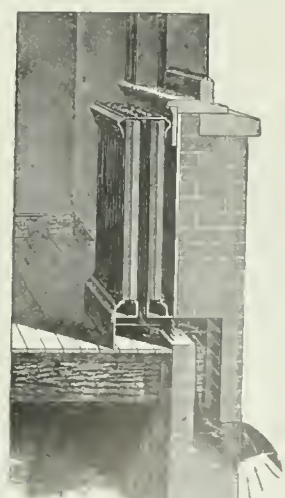

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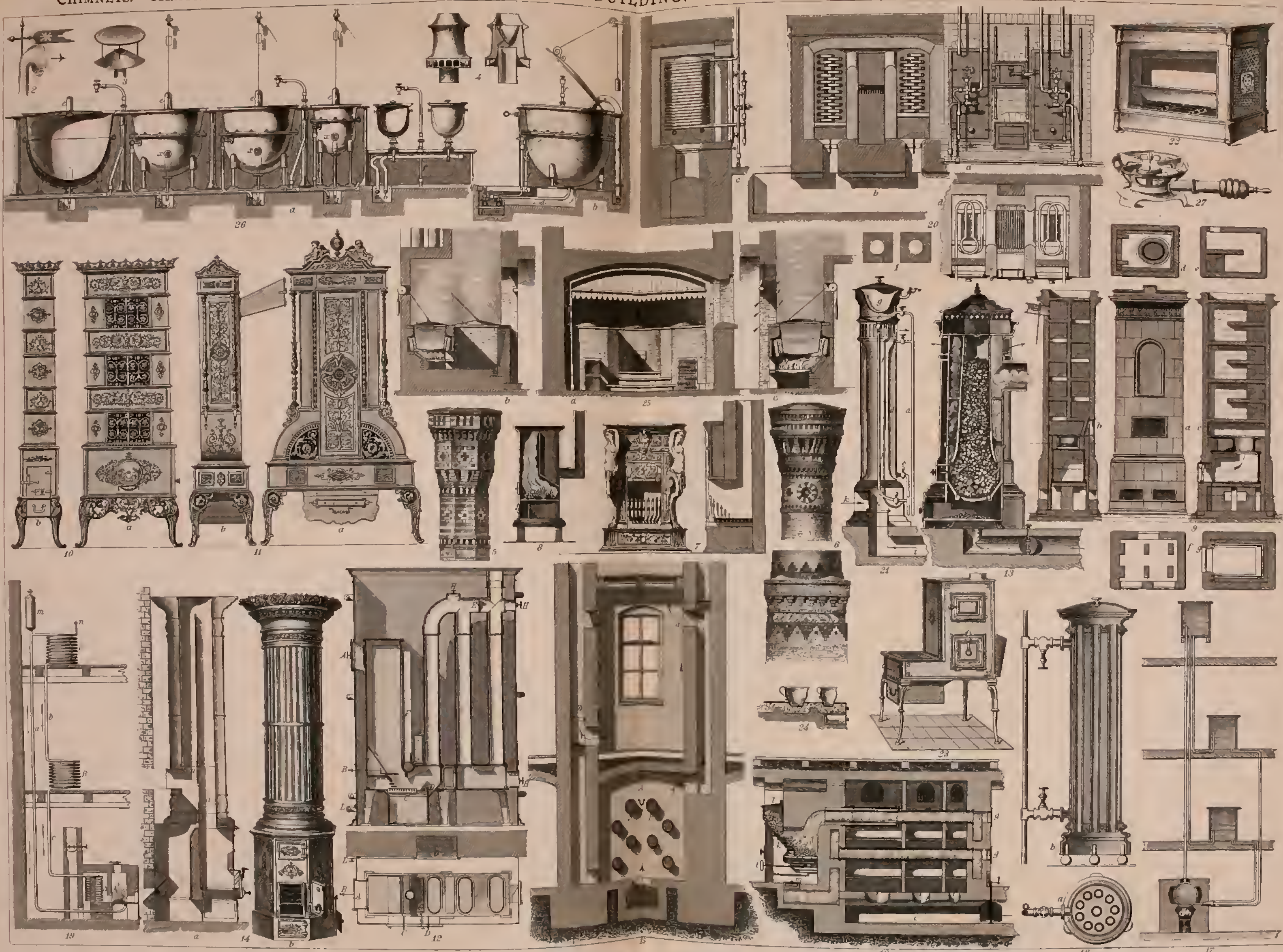
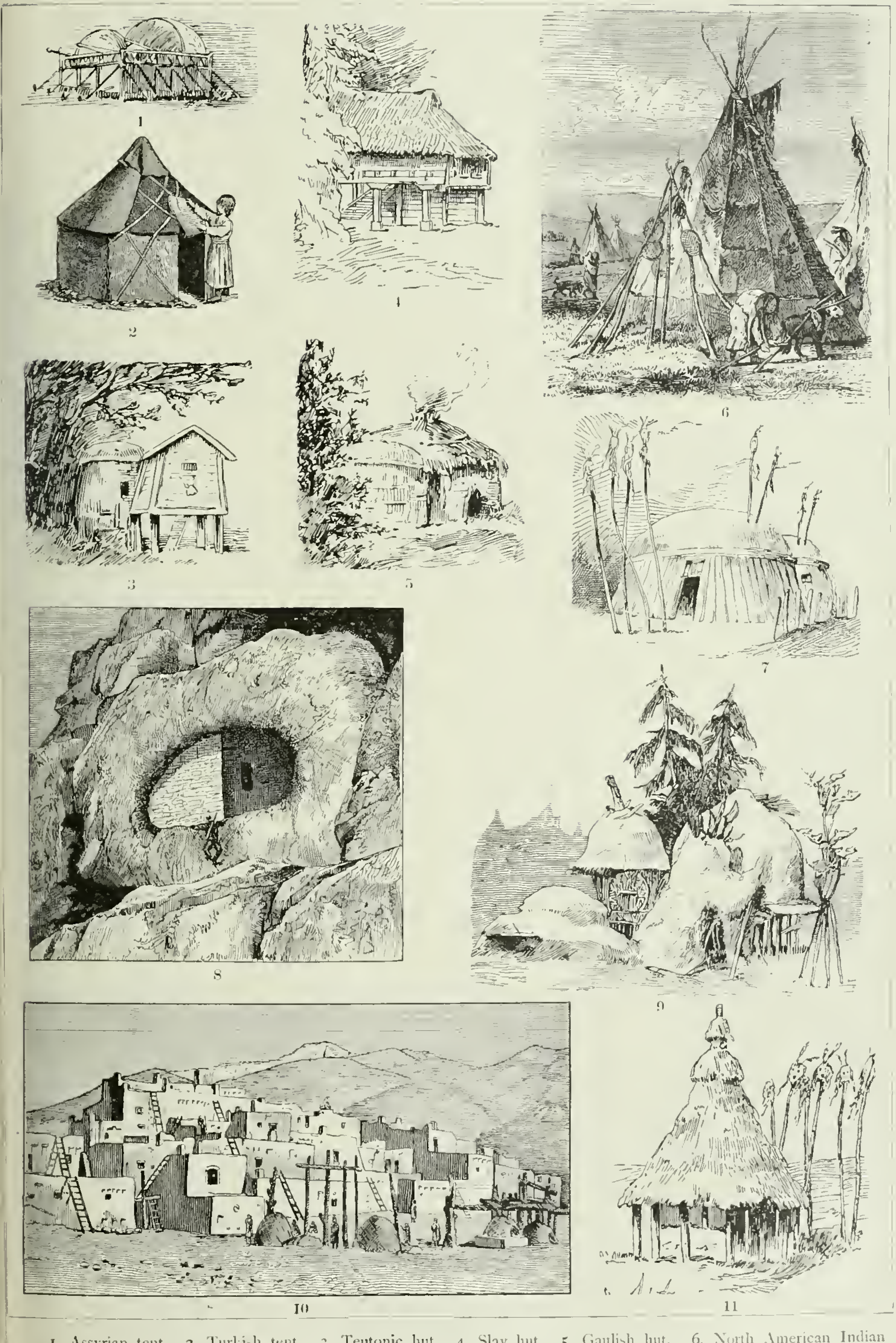
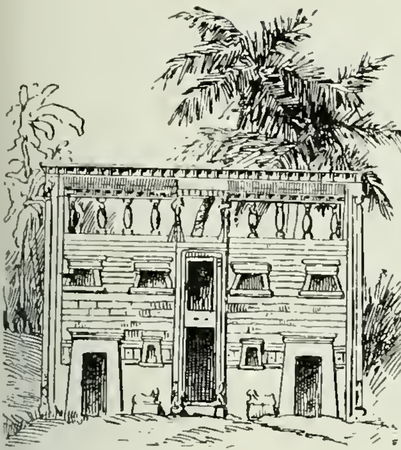
1. American gas-cooking range. 2. Cross-section, 3. Elevation, of the Gurney hot-water heating system. 4, 5. American cooking-ranges. 6. Harper's improvement for coal stoves. 7. American base-burning reservoir stove. 8. Franklin open-grate coal stove. 9. Brick-set hot-air heater. 10. Portable hot air heater. 11. Gurney hot-water radiator.



1–6. CHIMNEYS: 1. Ground-plan of a Russian chimney. 2. Movable chimney cap. 3. Stationary chimney cap. 4. "Deflector" chimney cap. 5. Octagonal factory chimney. 6. Circular factory chimney. 7–22. HEATING APPARATUS: 7. French open-grate fireplace (elevation and cross-section). 8. Barrel, or round, stove (vertical section). 9. Faïence stove with iron fire-box (*a*, elevation; *b*, *c*, vertical sections; *d*, *g*, horizontal sections). 10. Iron-stage stove (front and side elevation). 11. Iron self-feeding stove (front and side elevation). 12 Iron self-feeding jacket stove (vertical and horizontal sections). 13 Self-feeding coke stove (vertical section). 14 Regulator stove with jacket (*a*, vertical section. *b*, elevation). 15, 16. Ventilating hot-air heating apparatus (vertical section). 17 Low-pressure hot-water heating system. 18. Hot-water heating radiator (*a*, plan; *b*, elevation). 19. High-pressure hot-water heating (Perkins's system). 20. Haag's high-pressure hot-water heating furnace (*a*, elevation; *b*, longitudinal section; *c*, cross-section; *d*, plan). 21. Steam-heating radiator (vertical section). 22. Gas-heating stove. 23–27. COOKING APPARATUS: 23. Cook stove, or range. 24 Stove-plate for cooking utensils. 25. Cooking apparatus for public institutions. 26. Steam-cooking apparatus (*a*, longitudinal section; *b*, cross-section). 27. Portable gas-cooking stove.



1. Assyrian tent. 2. Turkish tent. 3. Teutonic hut. 4. Slav hut. 5. Gaulish hut. 6. North American Indian tent. 7. Pequod Indian wigwam. 8. Cliff-dwelling. 9. Laplander hut. 10. Communal dwellings of the Pueblo Indians. 11. South African hut.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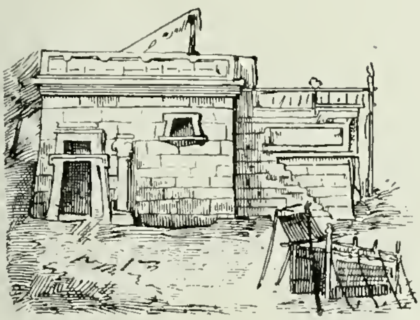
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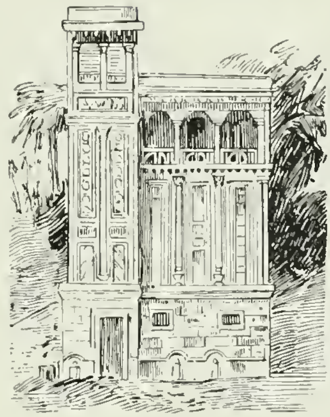
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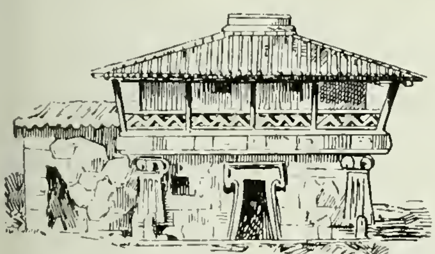
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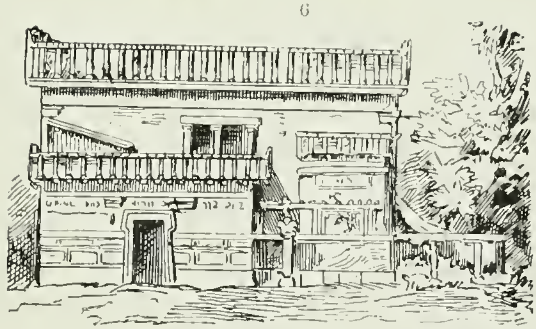
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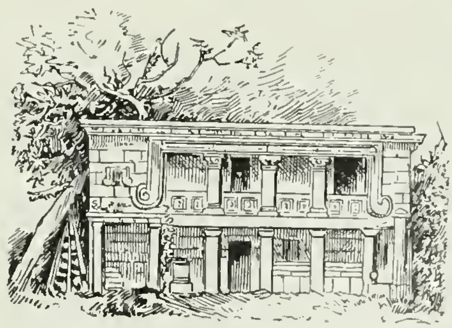
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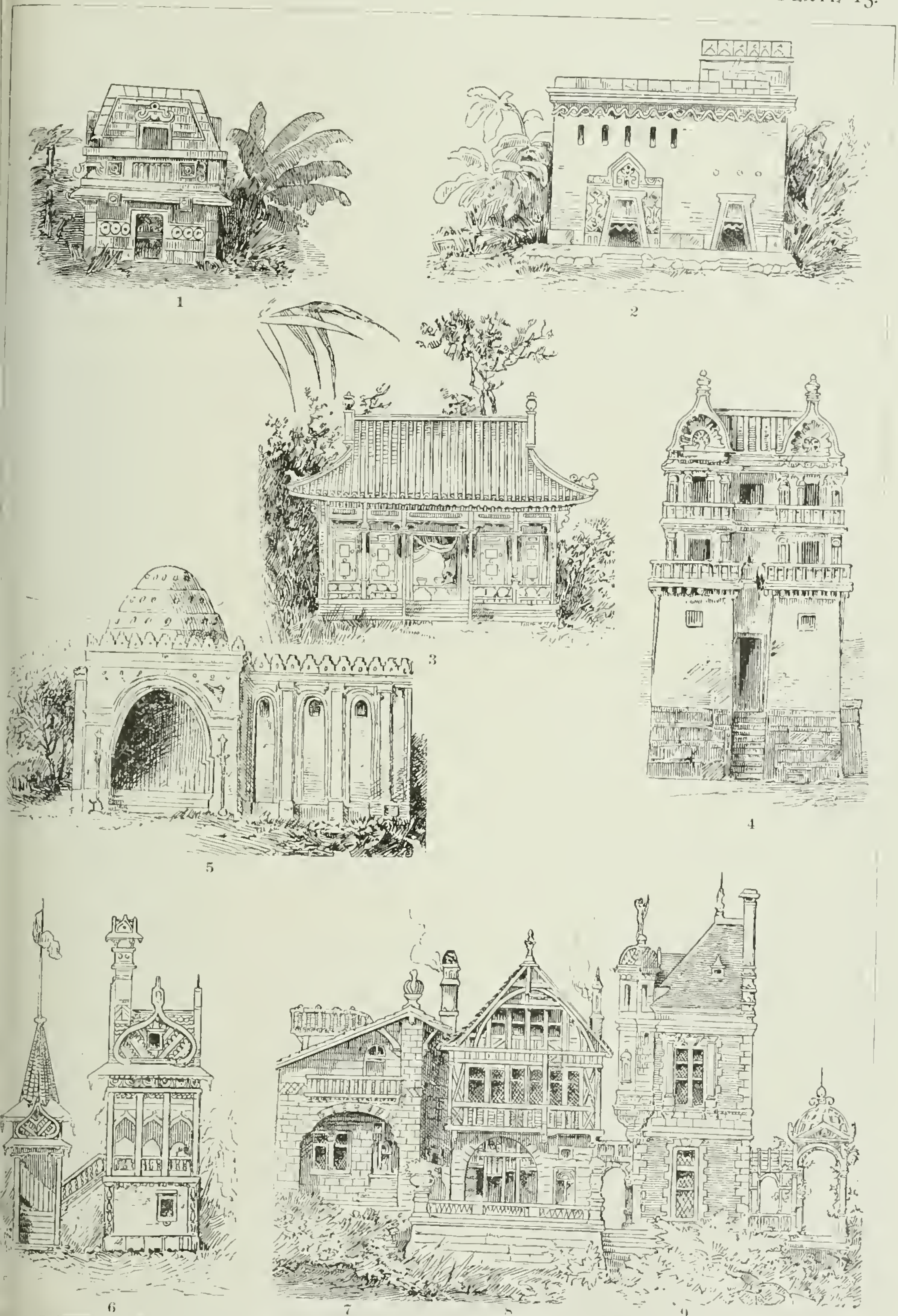
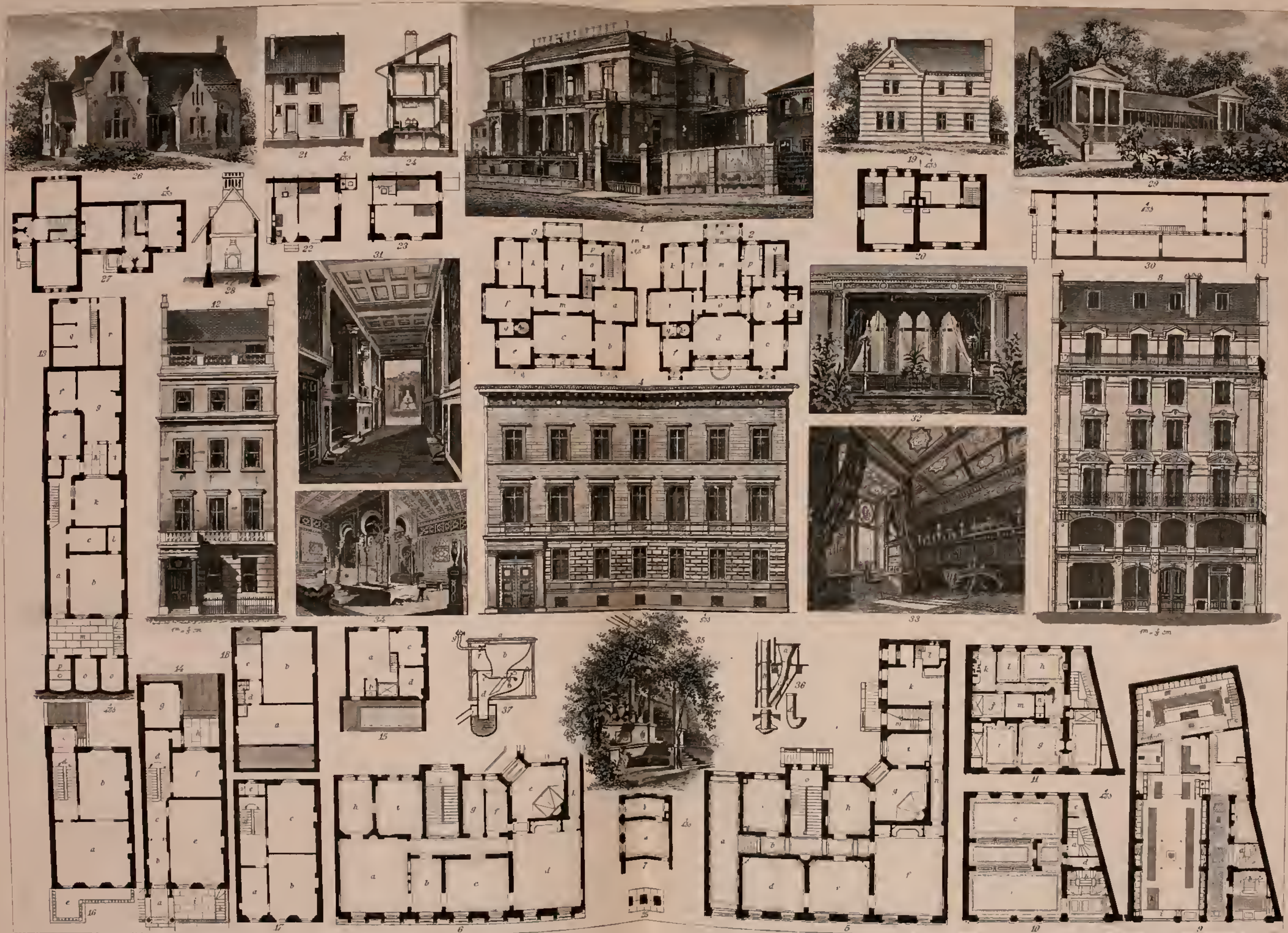
1. Egyptian dwelling. 2. Soudanese dwelling. 3. Assyrian dwelling. 4, 5. Hebrew house and tent. 6. Phœnician dwelling. 7. Etruscan dwelling. 8. Greek dwelling. 9. Roman dwelling. 10. Byzantine dwelling.



1. Aztec dwelling. 2. Ancient Peruvian dwelling. 3. Chinese dwelling. 4. Hindu dwelling. 5. Persian dwelling. 6. Russian dwelling. 7–9. Transition of architectural styles: 7. Romanesque, 8. Medieval, and 9. Renaissance dwellings.



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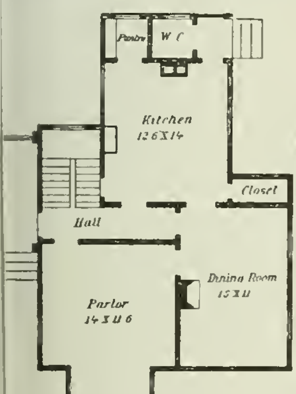

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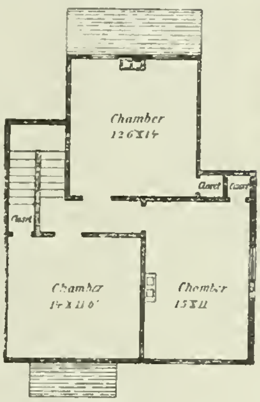

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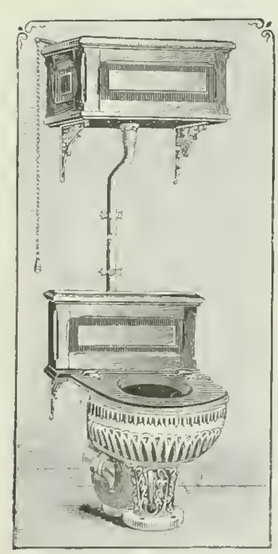

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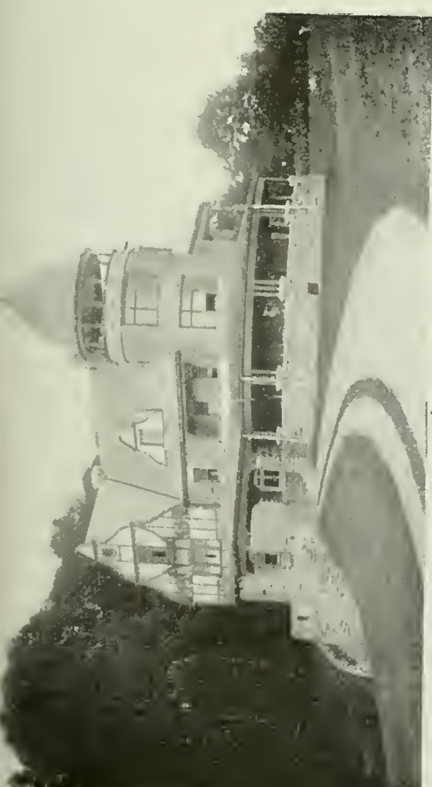
1. Perspective of modern-built two-story dwellings in Philadelphia (Thomas H. Parks, builder). 2. Elevation of odern-built three-story residences in Philadelphia. 3, 4. Plans, 5. Perspective, of a workingman's cottage of the Ludlow lass.) Manufacturing Company. 6. Improved water-closet fixture.



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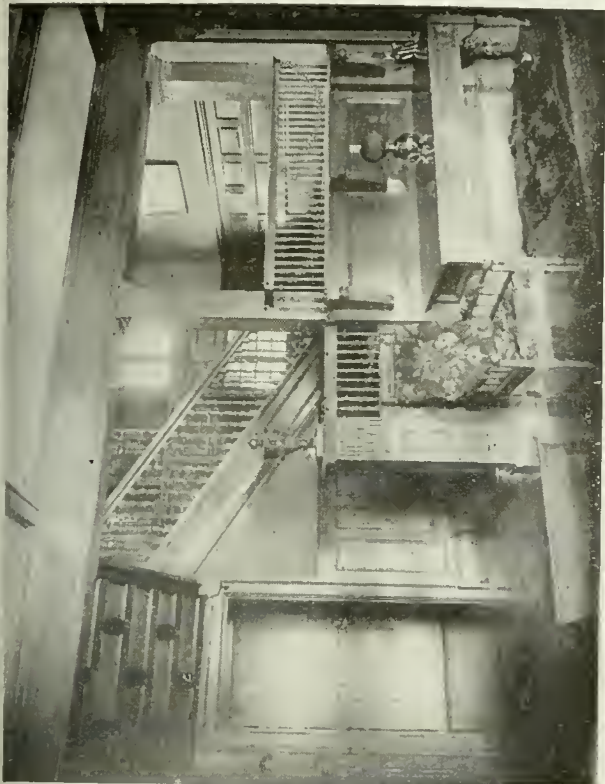

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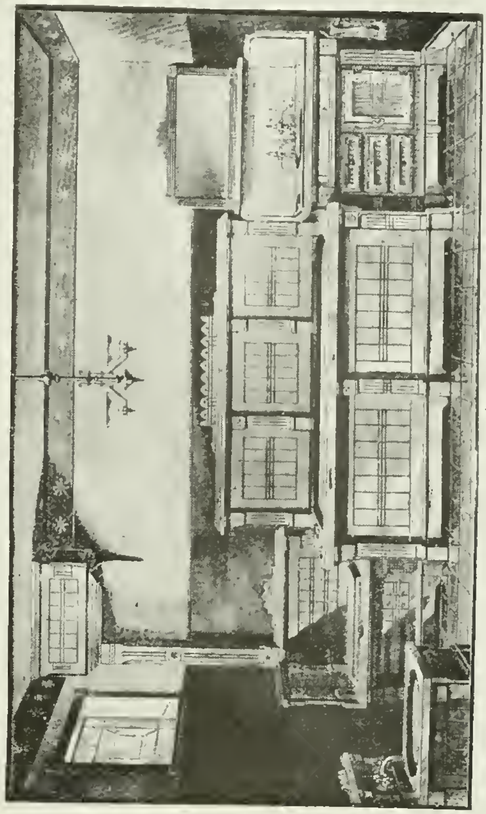

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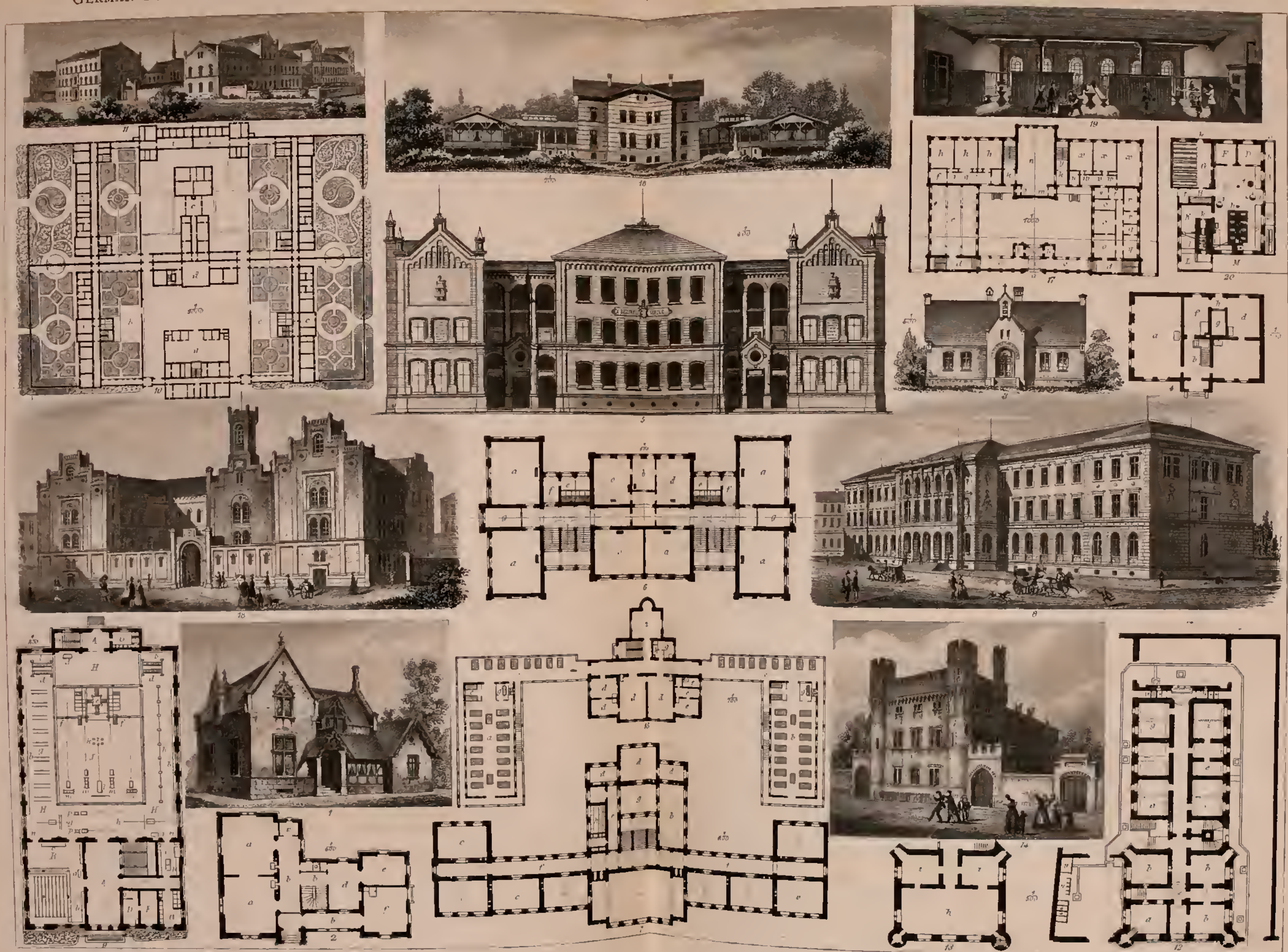
1. Suburban residence at Chestnut Hill, Philadelphia. 2. Parlor of a residence in Philadelphia. 3. Hall of a suburban residence (*fig.* 1). 4. Modern bath-room interior.



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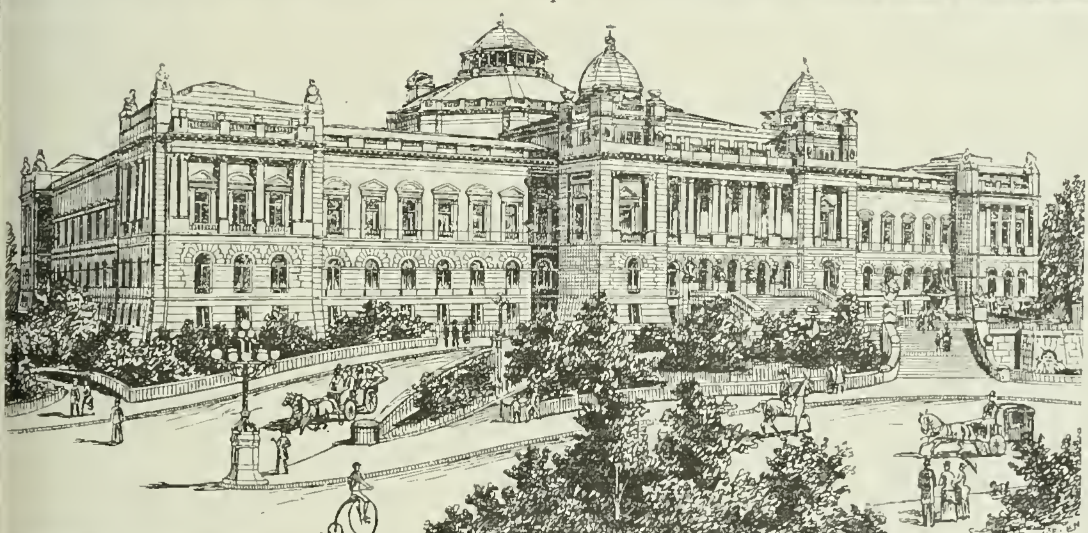

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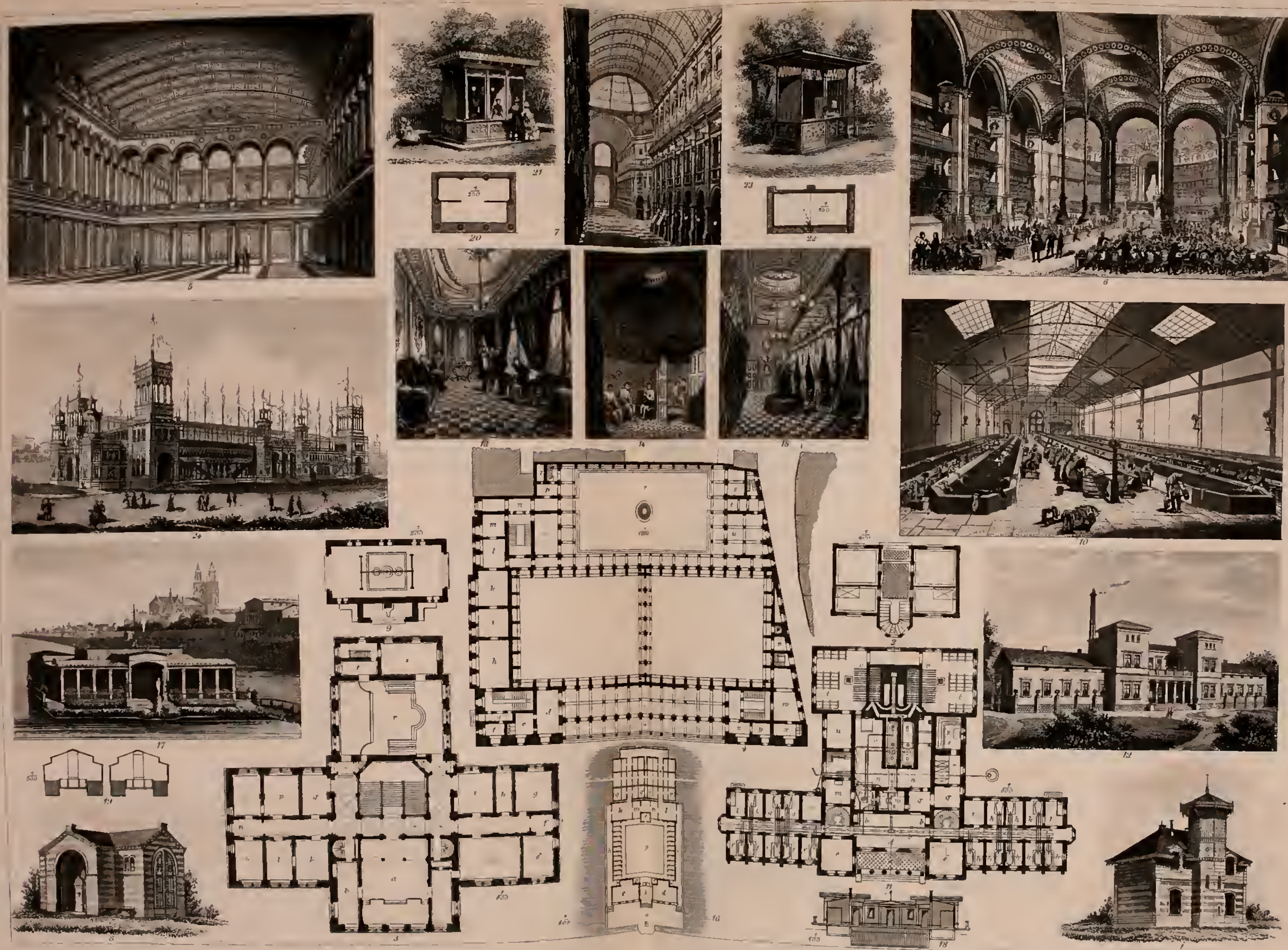
1. Hospital of the University of Pennsylvania, Philadelphia. 2. Perspective of the proposed Congressional Library building, Washington, D. C. 3. Perspective of the Main Building of the United States Centennial Exhibition (1876).



1. Perspective, 2. Ground-plan, of a French octroi-, or inland custom-, house at Lyons. 3. Ground-plan of the court-house at Bonn. 4. Ground-plan, 5. Interior, of the Exchange at Berlin. 6. Reading-room of the National Library at Paris. 7. Glass passage or arcade: the Galleria Vittorio Emanuele in Milan. 8. Perspective, 9. Ground-plan, of a force-pump house. 10. Interior of a public laundry in Paris. 11. Ground-plan, 12. Perspective, of a bath- and wash-house at Münster. 13. Reception-room, 14. Tepidarium and Sudatorium, 15. Frigidarium, of the Roman bath at Hamburg. 16. Ground-plan, 17. Perspective, 18, 19. Cross-section of swimming-basin and private baths, of the river bath at Magdeburg. 20. Ground-plan, 21. Perspective, of a Berlin mineral-water stand. 22. Ground-plan, 23. Perspective, of a Paris mineral-water stand. 24. Perspective of the festival-hall of the Sängerbundesfestes in Dresden (1865).

PART II.—ENGINEERING.

PART II.

ENGINEERING.

I. ROADS, STREETS, AND VEHICLES.

1. Roads and Streets.

THE Orient, the cradle of civilization, yields us the earliest references to artificial roadways. Those built by Semiramis are the first of which history makes mention, and an artificial road is known to have been built between the ancient cities of Susa and Sardis, a distance of about two thousand miles. The Carthaginians, a people noted for their commercial and military spirit, were also builders of roads, and the oldest Chinese works of this description were made so substantial and enduring that they are serviceable to the present day. The Greeks, particularly the Athenians, built excellent highways, certain of which, as the sacred road to Delphi, were dedicated to religious uses; at Cyrene, also, was a notable work of the same kind.

Roman Roads.—The Romans, however, far surpassed all their predecessors and all their contemporaries in the magnitude and excellence of their works of this character. Built primarily for the purpose of facilitating their vast military operations, to which they rendered most important aid, they were esteemed so essential that, notably under Augustus, Vespasian, and Trajan, highways were made from Rome to all parts of the Empire, even through regions where Nature had interposed the most serious obstacles. Imposing remains of these works, which may even yet be found in nearly every country of Europe, testify to the pre-eminence of the Romans as builders of roads. The care which they bestowed upon their great highways will appear from the following analysis of their construction. The base of the roadway was formed of one or two layers of stone laid in mortar (*statumen*); upon this followed a course of broken stone and mortar (*rudus*); over this was placed a layer of finely-broken stone with freshly-slaked lime (*nucleus*), which served as the bed of the stone pavement proper, composed of polygonal stone slabs (*summum dorsum*); or the stone pavement was sometimes omitted, in which case the third course of the road was formed of the largest obtainable cobbles, and the road-surface became *summa crusta*. In the Middle Ages the Roman roads were allowed to fall into decay, and, save in rare cases, no new ones were laid out.

Modern Roads.—Coming down to modern times, the building of roadways was begun first in Holland; afterward they were constructed in Spain and England. In Germany the first highway was built in 1753, between Oettingen and Nördlingen. About the same period much activity was displayed in France in the construction of works of this character.

The Earth Road.—Considering roadways in respect of the mode of construction, it will be proper to proceed from the crudest forms—the simple earth roads, or the rough temporary structures intended to facilitate the conveyance of heavy materials for industrial or military operations—to the established highways constructed in the most substantial manner and constituting the principal channels of trade. The earth road, which is common in all countries, and is necessarily the chief dependence for intercommunication in all new countries, is formed by excavating the natural soil from lateral ditches and spreading this out to constitute the covering of the roadway, the side-ditches serving for draining the surface. In many cases, especially where the soil is sandy or gravelly, no provision for other than natural drainage is attempted, and the road is simply a wagon-track on the natural surface of the ground.

Corduroy Roads.—For the passage of swamp- or marsh-land the expedient usually is adopted of forming for vehicles a roadway of straight logs, either round or split, whose length is suited to the required width of the road; these logs are laid side by side, the joints or openings between them being levelled up as evenly as possible with smaller pieces having the same length as the larger logs, but split to a triangular cross-section and inserted into the interstices with one edge down, so as to form a flat surface. In the United States such roads are called "corduroy roads." A modification of the corduroy road is the timber causeway shown in Figure 1 (*pl.* 20).

Plank Roads.—In countries where lumber is plenty and cheap, plank roads are in use. They are commonly made by laying down, lengthwise of the road, parallel rows of planks (called "stringers" or "sleepers") about 5 feet apart between centres, which serve to support cross-planks laid upon them. A section of such road is seen in Figure 2. Plank roads were in very common use in the United States twenty-five or thirty years ago, and are still by no means rare; they are in vogue also in Russia. When new, they afford great convenience for heavy haulage, and, though lacking in durability, as temporary expedients in newly-settled districts they have their *raison d'être.*

Stone Roads.—In modern forms of road-construction a distinction is made, based on the character of the road-covering, between roads whose surface is formed of broken stone in small fragments and roads whose surface is composed of prepared blocks of regular form. The first are used chiefly for country roads; the last, for the streets of cities. Roads of broken stone have been variously constructed at different periods and in different countries, as the following historical summary will exhibit.

Tresaguet's System, introduced in France toward the close of the eighteenth century and still in use in some districts, is shown in Figure 3. The road-bed is prepared by removing a section of earth of suitable width and depth to form the body of the road, which, after proper levelling and compacting with rammers, to give it a horizontal or slightly-arched form, constitutes the floor of the road-bed. At the side are laid border-stones, which serve to establish the surface-level, and between these is laid a sub-pavement of wedge-shaped stones about 4¾ inches thick and 11¾ inches high, flat side down and tapering parts upward. The spaces between the apices of these pyramidal stones are filled out with smaller stones, which are driven down with a heavy rammer until the top of the foundation-layer has assumed a tolerably uniform surface. Upon this is placed a layer of rather coarse yet evenly-broken stone, which is gone over several times with a roller of about 60 cwt., and upon this, in turn, comes the top layer of finely-broken stone, evenly spread and levelled, first with a roller of 60 cwt., which for finishing should be followed by one of 150 cwt., or even heavier.

Macadamized Roads.—In the early portion of the present century England contributed greatly to the advancement of road-building through the labors of Macadam and Telford, who were the pioneers of good road-construction in the United Kingdom, and whose methods have since been more or less closely copied. In the system recommended by Macadam, and since known by his name, the road is constructed entirely of layers of stone broken into fragments of uniform size and approximating the cubical form (the largest of which should not exceed 1½ or 2 inches in its greatest diagonal length); the successive layers are then evenly rolled down. The present practice is to prepare at once a comparatively hard surface for traffic. A road of this construction is exhibited in Figure 4 (*pl.* 20). If stone of the best quality cannot be had for the entire road-body, the hardest and toughest materials should be reserved for the upper layers—say to the depth of 6 inches. Macadamized roads are in very general use in Great Britain and on the Continent, and to some extent also in the United States. They cost comparatively little for maintenance, and they present a surface so compact that water will penetrate it only with difficulty.

The Telford Road, in general principles of construction, is not unlike that of Tresaguet, above described, in being formed of a sub-pavement of stone blocks with layers of broken stone. The materials laid upon the bottom course were, like Macadam's materials, angular fragments of hard stone broken into small pieces, gradually decreasing in size toward the top, where they formed a fine, hard surface.

Character of the Road-bed.—The thickness that should be given to a roadway of broken stone must be determined by such considerations as the supporting power of the soil, the climate, the hardness and toughness of the stone covering, and largely by the kind of traffic it is intended to sustain. It is safe to assume that a road-bed of well-consolidated materials, if designed for heavy traffic, should have a thickness of from 10 to 12 inches; if designed for light traffic only, the thickness may be reduced to 6 or 8 inches. French road-engineers consider 10 inches sufficient in France for the most important roads. Macadam's practice varied from 6 inches as a minimum to 10 inches as a maximum. The surface of the stone roadway, that it may quickly shed water, must be given a suitable inclination from the centre toward the sides; so that its cross-section may have a slightly-arched form, varying in degree of curvature according to the grade—flatter where the grades are steep, and *vice versa.*

The material constituting the road-covering should be hard, tough, and durable, non-absorbent of water, free from clay or other earthy admixture which would interfere with the proper interlocking of the broken stone, and capable of yielding good cubical fragments with the minimum of spalls and splinters. The best road-coverings are furnished by quartzite, the basaltic, doloritic, and other trap-rocks (greenstone), and the hardest and toughest feldspathic rocks, such as porphyry, syenitic granite, etc.

Gravel Roads.—Where good material for macadamized roads is not accessible, gravel affords a fair substitute; indeed, with proper attention to construction, this material possesses all the essential requirements of a good roadway. Gravel roads, if subjected to heavy traffic, are inferior to those of broken stone, but for light traffic and where they are properly maintained, they are in all respects admirable. They are very popular for suburban and park roadways. The directions laid down by Gillmore in his treatise on *Roads, Streets, and Pavements* concisely state the conditions to be observed in the building of a good road of this material. This authority calls special attention to the capital distinction that should be made between gravel that will pack under travel and clean rounded gravel that will not pack. The packing quality of the first sort is due to the presence in it of a small proportion of clayey or earthy material; while seaside and river-sand gravel, being composed almost entirely of water-worn and rounded pebbles of all sizes, which slide easily upon one another, will not pack unless some material possessing a binding quality be mixed with it. Pit-gravel, on the other hand, usually contains too much earthy matter. The gravel for the top layer, at least, should be hard and tough; otherwise, the material will soon be pulverized, making the road very dusty in dry weather and very muddy in wet weather. It should be composed of particles from ½ to 1½ inches in dimensions, and should contain enough sandy and clayey loam to bind the particles together firmly.

Construction of Gravel Roads.—In preparing the bed of a gravel road, an excavation should be made to the depth of 10 or 12 inches, and of the proper width, to receive the gravel. This is where the road-bed is in soil. Where the bed is rock, it is recommended to interpose between it and the gravel a layer of earth, to prevent the gravel from wearing too rapidly. The surface of the sub-grade thus excavated should preferably be given the same slope from centre toward the sides as that intended to be given to the road-surface. The bottom layer should be of unscreened gravel, about 4 inches thick, evenly raked on the entire surface and then compacted by the use of a road-roller. The roller used for this purpose and for the preliminary consolidation of the upper layers should not be heavier than one and one-half to two tons; a much heavier roller (five to seven tons) should be used for the top layer. When the bottom layer has been made tolerably firm, a second layer of 3 or 4 inches' thickness is laid on, and treated in the manner above described; and this operation is repeated until the roadway has received the required height and form. The top layer should be of screened gravel of the quality spoken of above, and the thickness of the entire bed, when properly consolidated by rolling, should be about 12 inches. Provision for drainage must be made by means of side-ditches; and where such a road has been constructed upon soil of a loose or porous texture, these will usually suffice to drain the road thoroughly to the depth of a foot or more below the bottom of the bed; where the sub-soil will not admit of such free drainage, this should be facilitated by cross-drains introduced at proper intervals below the road-covering.

Deterioration of Roads.—The stone roadway is no sooner given over to traffic than it is subjected to destructive influences. These are partly physical and chemical, due to the atmosphere and weather, but chiefly mechanical, due to the wheels of vehicles and the hoofs of horses, which abrade and crush to pieces the superficial layer of stone. In dry weather this pulverized material forms a disagreeable dust which the rain converts into mud. If this is allowed to accumulate in considerable amount, it seriously impedes traffic by forming ruts, and acts injuriously upon the road itself by retaining moisture upon its surface. A thin coating of pulverulent material is not objectionable—on the contrary, may even be advantageous as a species of protection to the surface of the roadway; but when this has exceeded a certain limited thickness, its removal becomes absolutely necessary.

Traffic and Maintenance.—The capacity of a given roadway to support a given amount of traffic stands in close relationship with the condition in which it is maintained. This is so well known that, in the leading European countries, excellent systems of road-administration are in vogue, certain features of which might with much advantage be copied in the United States, where the subject of the proper maintenance of roads rarely receives the attention which its importance demands.

Measured in terms of the life of draught-animals and the wear and tear of vehicles, the advantage of maintaining roadways in the highest condition would be evident from economical considerations alone, as the following example, given by Gillmore, will demonstrate: Take the case of a well-made broken-stone road clean and dry, and compare it with the same road in a wet and muddy condition. It appears from the formula established by Sir John Macneill that "a stage-wagon weighing 1500 pounds, in order to carry a load of 1500 pounds at the rate of 5 feet per second (3⅓ miles per hour), will require the constant exertion of a force of 94¾ pounds on the dry and clean road; while to move it at the same rate on the same road in a muddy state will require the constant exertion of a force of 119¾ pounds."

Here, therefore, is an increase of about 28 per cent. of force expended, which increase is due entirely to the neglect of the condition of the road-surface. Taking the case of a road between two cities, ten miles apart, and assuming that a certain amount of freight will have to be conveyed over the road each day, whether the road be in good or bad condition, it has been established that if the assumed traffic could be carried without unusual fatigue by the daily service of fifty-four draught-animals when the road is in good condition, clean and dry; when the road is covered with dust the number of animals required to perform the same service will be increased to sixty-three; and when this dust is converted into mud, the number required will be sixty-nine.

From these data it is calculated that the *extra cost* of conducting the traffic on the road, due to its neglected condition, will amount to five thousand dollars per year. In this comparison the same road-bed has been under consideration—a good substantial one—in the one case kept clean, and in the other covered with dust or mud. If the comparison be instituted between a good road and an inferior one, the contrast will be even more instructive. The accompanying tabular statement, based on the experiments of M. Morin, exhibits the actual relation of animal force to traffic on different kinds and conditions of roads. The load and vehicle are assumed to be the same in each case:

KIND AND CONDITION OF ROAD.	Relative number of horses required for a given traffic.
Broken-stone road, very dry and smooth	50
Oaken platform, or plank road, in good condition	59
Broken-stone road, moist and dusty	71
Causeway of earth, or dirt road, in good condition	93
Broken-stone road with ruts and mud	112
Broken-stone road with deep ruts and thick mud	192
Solid causeway of earth covered with 1½ inches of gravel	245

Width of Roads.—In respect of the width of roadways there is no fixed rule. This will depend upon the amount and nature of the traffic that the road is calculated to sustain. The narrowest roads are found in mountainous districts, as in Switzerland, the Tyrol, etc. In Germany the width varies from 60 feet (including foot-way) to 20 feet, for roads intended for heavy teaming. In Prussia the width varies from 40 feet to 25 feet. In France there are four classes of roads: (1) 66 feet in width, of which 22 feet in the middle are stoned; (2) 52 feet, of which 20 feet are stoned; (3) 33 feet, of which 16 feet are stoned; and (4) 26 feet, of which 16 feet are stoned.

In England the roads are comparatively narrow, the average being about 25 feet. In the United States there is no uniform practice. The rules laid down by Gillmore are followed in a general way in the well-populated districts. These are as follows: For the principal thoroughfares prepared for vehicles between cities and large towns a width of from 27 to 30 feet will be ample, but this width should be increased within or near the cities to 40, 50, or even 60 feet, where the amount of traffic is large and where there is considerable light traffic and pleasure-driving. For cross, branch, and ordinary town and country roads the width of the stone-bedded portion may be reduced to from 16½ feet to 17 feet, which will be sufficient for two wagons of largest width to pass each other without danger of collision. The width of the principal streets of cities is usually greater than that of the roads above described. In this particular certain American cities afford conspicuous examples.

Passing now to another branch of the subject—namely, paved roadways in towns and cities—a number of diverse systems demands consideration.

Paved Roads.—Where stone is used for the purpose, the material should possess the needful hardness and durability for its intended service. It should likewise permit of being readily dressed into blocks of regular form. Granite and the hard and dense varieties of sandstone and limestone, in the order named, are found best suited for this service. Where these are not available, rubble and cobble-stones are frequently substituted therefor, though these make a much inferior pavement. A good stone pavement is more costly to lay than a macadamized roadway, but affords an easier surface for traction and is less expensive to maintain.

Paving-stones.—The quality of a stone-paved street depends largely upon the form, size, and mode of setting the paving-stones employed in its construction. In the most approved system, where the stones are laid in regular lines or courses, they are given the form of rectangular blocks, sometimes slightly tapering toward the lower end (*pl.* 20, *figs.* 5, 6). The smoother the blocks, the more intimate will be the contact between them, and consequently the more solid the resulting structure. In respect of size there is some difference in practice, but it may safely be stated that, to afford the best possible foothold for horses, the individual blocks should be no broader (in the direction of the draught) than the length of a horse's shoe—that is to say, from 4 to 4½ inches, as a maximum. Their depth from top to bottom should be sufficient to avoid any disposition to tilt to one side when a weight comes upon the other—and for this dimension a little more than twice the horizontal breadth has been found a good proportion—and their length crosswise of the street, to insure an ample area of bearing-surface on the foundation, should be at least equal to their depth, and may advantageously be somewhat greater than this.

From these data the most approved dimensions for a paving-block would therefore be as follows: Breadth (measured along the street), from 3½ to 4½ inches; length (measured across the street), from 9 to 12 inches, or even 15 inches; depth, from 8 to 10 inches. The stones are laid closely in contact on edge and in continuous courses, the direction of the individual courses being usually directly across the street (*fig.* 8). Sometimes they are laid at an angle of from 45° to 60° with the axis of the street, with the object of lessening the tendency to wear into a convex surface. On the steep grades the plan of laying the blocks in two sets of diagonal courses is sometimes followed, as is shown in Figure 1 (*pl.* 21). The courses meet in the centre of the street, with the angle pointing up the incline. The joints slope downward and facilitate the drainage by directing the surface-water, right and left, into the gutters. In all cases the successive courses must be laid so as to "break joints" (*pl.* 20, *fig.* 8).

Foundation of Paved Roads.—In respect of the foundation, this may be concrete, or rubble-stone filled in with concrete, in which case it is recommended by the best constructors to lay each stone solidly in a bed of cement-mortar, and to use the same material or bituminous mortar between the joints; or the foundation may be of sand or gravel, or of broken stone. In the latter case the paving-stones are set in a layer of sand or gravel spread evenly on the foundation, after which they are rammed with a heavy wooden rammer, and the finished surface is then covered with a thin layer of clean sand or fine gravel, which gradually works its way between the joints in the pavement (*pl.* 20, *figs.* 5, 6). Where, from scarcity of suitable material or for economic reasons, stone blocks are inadmissible, recourse is had to cobble-stone or rubble-stone as a substitute.

The Cobble-stone Pavement is formed of rounded, water-worn stones, usually egg-shaped, which are selected so as to be as nearly uniform in size as possible; the best material averaging from 6 to 10 inches in length and from 3 to 6 inches in width. These stones are set as close to one another as possible, with the smaller ends down, in a foundation formed of a bed of sand or fine gravel, which should be from 8 to 10 inches deep. After they have been set in position the cobbles are rammed down firmly, to give a uniform and slightly convex surface, and over the surface is spread a layer of sand or fine gravel, which works its way in between the stones. This form of pavement is in very common use throughout the United States, but is much inferior to the stone-block pavement.

The Rubble-stone Pavement is composed of stone fragments of various irregular shapes and sizes laid as closely together as possible; the appearance of such pavement is shown in Figure 2 (*pl.* 21). Stone suitable for this purpose may generally be obtained with little difficulty from the refuse of stone-quarries. The flat surfaces of such material afford a better foothold for draught-animals than the rounded surfaces of cobbles, and less tractive power is required than on the latter. As compared with the cobble-stone, therefore, the rubble pavement is preferable. The best sizes for the rubble-stone are a breadth of from 3 to 6 inches, a length of from 6 to 12 inches, and, as a minimum for stability, a depth of 6 inches. The rubble pavement is laid in the same manner as the cobble pavement, on a foundation of sand or gravel, each stone being carefully placed in position by hand and the entire surface afterward rammed down to the required level. The stone pavement is terminated laterally by the curb, which serves both as the limit for the sidewalk and as the side-wall for the gutters, which run along the sides of the street and serve to drain it through openings, placed at proper intervals, which communicate with the sewers. To facilitate drainage the street is given a slightly-arched form in cross-section.

Tile Pavements.—In the Netherlands and the coast-region of Hanover and Oldenburg, in default of suitable material for stone pavements, hard-burnt tiles are made to serve as a substitute (*pl.* 20, *figs.* 7, 9). Before setting these tiles, the foundation, which is made of the most porous materials obtainable, is carefully rammed or rolled, and is then scraped off into the proper arched section with a scraper. The curbstones in this construction are formed either of natural stones or of several rows of tiles set on edge. The finished roadway commonly receives a thin covering of sand.

Cast-iron Pavements have been tried experimentally, but the result has not been sufficiently satisfactory to encourage their general adoption. Figures 12 and 13 (*pl.* 20) exhibit the appearance of such a pavement laid down in New York City. It was formed of cast-iron blocks, each having the form of two concentric cylinders strengthened with radial connecting-ribs. The vacant spaces were filled with hard-rammed earth or gravel. Figures 16 and 17 represent a cast-iron cellular pavement with connected ground-plate.

Wooden Pavements.—Pavements of wooden blocks, usually placed on a foundation of wooden flooring, have been extensively introduced. They were at one time extremely popular in the United States, and were in use in nearly every important city (notably in Washington and Chicago), but of late they have fallen into disuse. On the other hand, they appear to be growing in favor in Europe, and have recently been adopted to a considerable extent in Berlin and other cities of Germany.

Asphaltum Pavements.—Streets and roadways of asphaltum have been laid down in Paris, London, Berlin, and other European cities, and in many of the cities of the United States, Washington being a notable example. The London asphalt pavement is made of a layer of freshly-ground asphalt, 2 inches thick, laid upon a foundation of 8 inches of concrete and compressed by the use of heated iron rollers. The powdered asphalt is laid on very hot, but not melting, and after compression and cooling at once assumes the solidity of the natural rock-asphalt. The high price of this material has led to many attempts to prepare artificial substitutes, for which purpose mixtures of tar, pitch, and granulated limestone have commonly been resorted to. In the United States enormous sums have been squandered in experiments upon various form of concrete and mastic and pseudo-asphalt pavements. These have commonly been called asphalt pavements, although usually composed of coal-tar, pitch, etc. These expensive failures served for a time to bring the merits of the true asphalt pavement into disrepute. The disposition of such inferior substitutes to soften and to become sticky in hot weather explains the appropriateness of the name "poultice" pavements, which was coined to describe them.

The true rock-asphalt is a limestone saturated with about 12 per cent. of bitumen so thoroughly as to be hard, tenacious, and waterproof. Asphaltum itself is an oxidized hydrocarbon found in Trinidad and other localities. It is brownish in color, tough and hard, and withstands a temperature of 170° Fahr. unaltered. In many of the chief European cities roadways and footways made of the natural rock-asphalt, disintegrated by heat and afterward mixed with suitable proportions of the free bitumen to form a mastic, are found highly satisfactory. In the United States, asphaltum pavements of unexceptionable quality, both for streets and for sidewalks, have lately come into vogue. The asphalt employed is that from

Cuba or Trinidad. The city of Washington especially is well paved with asphaltum roadways.

Stone, Asphaltum, and Wooden Pavements Compared.—The following conclusions respecting the relative merits of the principal varieties of roadways in cities—namely, stone-block, wood, and asphaltum—appear to be warranted by experience. Denoting the asphalt, the stone-block, and the wood-block by their respective initials, A, S, and W, they may be arranged as follows, in the order of their excellence:

Ease of traction	A	W	S
Minimum destruction of vehicles	A	W	S
Comfort to driver	A	W	S
Foothold to horses, dry	W	S	A
" " " wet	A	S	W
Freedom from noise	A	W	S
" " dust	A	W	S
" " mud	A	W	S
" " exhalations	A	S	W
Facility of cleaning	A	S	W
Durability	S	A	W
Accessibility to pipes and relaying	S	A	W

Sidewalks and Crossings.—Respecting sidewalks it is unnecessary to say more than that they are commonly laid out so as to be slightly elevated above the level of the street, the surface-covering consisting of flagging, bricks, etc., with a good fall toward the curb for drainage, the object being to render them passable with the least inconvenience and personal discomfort at all times, in wet and dry weather. In certain cities, where the street traffic is so great as to make the crossings dangerous for foot-passengers, it has been found necessary to throw an elevated footway across the street. A crossing of this kind is shown in Figure 31 (*pl.* 20), which exhibits a structure that was at one time thrown across a much crowded portion of Broadway, in New York City. Upon country roads the material excavated in forming the road-bed and the drainage-ditches is commonly disposed at one or both sides of the road, thus constituting one or two banks which serve as footways.

Mechanical Appliances: Stone-crushers.—For preparing road-material at low cost and in quantity, mechanical appliances of various kinds are employed. Of these one of the most effective is the Blake stone-crusher, an American invention which has come into very general use (*figs.* 18, 19). This machine has a strong frame of cast iron which serves to support the working-parts. In Figure 18 one side of this frame is removed to exhibit the construction. The frame carries in suitable bearings a shaft having a double fly-wheel, and on one end a driving-pulley which receives a belt from a steam-engine. Between the bearings the shaft is furnished with an eccentric. To this eccentric shaft is attached a heavy rod, or pitman, connecting with two toggle-levers. On the forward end of the frame there is a fixed jaw, against which the stones are crushed. Opposite to this is a movable jaw, pivoted at its upper end, its face placed at an acute angle with that of the fixed jaw, leaving between the two faces a wedge-shaped orifice or passage, through which the broken stone is forced to pass.

At each revolution of the eccentric shaft the rod or pitman rises and falls, actuating the toggle-levers, which in turn cause the movable jaw to advance a short distance toward the fixed jaw, and to return by its own weight when the pressure of the toggles is withdrawn. This return-movement is aided by the elasticity of a rubber spring connected by means of a rod with the lower end of the movable jaw. It will appear that a stone dropped into the wedge-shaped opening between the jaws will be broken at the next bite, and, falling lower down, will be broken again and again with each succeeding bite, until the fragments pass out at the bottom as shown. By adjusting the wedge—seen at the back of the machine—inserted between the end of the frame and the toggle-block, the opening between the jaws may be regulated so as to cause the machine to deliver the broken stone of any required size.

The machine delivers the crushed stone into a revolving cylindrical screen placed in an inclined position. The meshes of this screen are very small at the upper end, and from 2½ to 2¾ inches square in the middle and lower portions. By this arrangement the dust and fine particles are screened out in the upper end, while the uniformly-broken fragments pass through the meshes of the lower part and are ready, without further preparation, to serve for road-material. The few larger fragments which may have escaped proper crushing, and which, being too large to pass the screen, issue from the lower end of the cylinder, are returned to the machine to be broken again.

The jaws of this machine are commonly faced with case-hardened blocks of iron, which can be turned over when worn and cheaply replaced when necessary. These working-faces as a rule are channelled with a series of coarse vertical furrows placed so that the ridges of one face are opposite the depressions of the other; the obvious intention of this artifice is to prevent the passage of long and and slender fragments of rock. Where the nature of the work makes it expedient, several machines are employed—a large crusher to break the rock into pieces of moderate size, and a smaller one to reduce these to the required size. These machines are commonly speeded to make from 200 to 250 revolutions per minute. They are built of various sizes, ranging from four to twelve horse-power, and in capacity from 3 to 7 cubic yards of broken stone per hour.

Gravel-screens.—For sorting material, such as pit-gravel, etc., containing pebbles of all sizes, two wire screens are commonly used, having meshes of different aperture. The largest pebbles, which will not pass the first, may be rejected or broken to smaller dimensions; the earthy and other foreign material that passes the second screen may answer for the sub-layer, while that which is retained by the second screen, preferably after another screening, will be reserved for the road-surface. Screening-machines for sorting such fine and coarse materials are sometimes employed.

One of these, a German machine devised by Augustin, is shown in Figure 20 (*pl.* 20).

Road-rollers.—The construction of compact and durable roads of broken stone has been rendered practicable only since the introduction of the road-roller (proposed by Cessart in 1787, and in universal use since 1830). The effect of proper rolling in consolidating the materials of the road-bed will best be understood from the statement that the vacant spaces between the individual fragments in unrolled roads are at least three times greater than in rolled roads. The improved road-roller in present use consists of a hollow cylinder of cast-iron, which, compared with the solid stone roller, has several advantages, the chief of which lies in the fact that it admits of having its weight gradually increased—an important feature in connection with the serviceability of this apparatus. The increase of weight of the roller is effected either by weighting-boxes (*pl.* 20, *figs.* 21, 22)—which may be loaded with stones, sand, and the like, and which for convenience of filling and unloading should be carried as low down as possible—or by filling the hollow cylinder itself with broken stone, sand, or sometimes with water (*fig.* 23). When the cylinder is charged with water, it is almost needless to add that precaution must be taken to guard it against freezing.

In order to facilitate the hauling of the roller over rough roads and to guard against its upsetting, the framework is provided with wheels adjustable in height in relation to the axis of the cylinder (*figs.* 21, 22). This provision is unnecessary with rollers of moderate size. To avoid the turning of the heavy roller every time it is required to go about in the opposite direction, the frame is sometimes fitted with a tongue or shaft on both sides; or the frame is made in the form of a ring, with which the tongue has a swivelling connection, so that the horses can carry the tongue around with them to the opposite side of the roller without being unharnessed.

In the German practice of road-making, the weight of the roller may vary from two and one-half tons unloaded to ten tons loaded. Gillmore, who is good authority in American practice, commends for gravel roads a roller weighing from one and one-half to two tons for the bottom layers, a six-ton roller for the top layer, and for macadamized roads a twelve-ton roller. The heavy roller constructed for the New York City Department of Parks weighed six and one-half tons and could be loaded to twelve tons. It was built of two hollow cylinders of cast iron set abreast on a strong wrought-iron axle, working together a length of 5 feet, with a diameter of 7 feet. The cylinders were set in a timber frame, and in the ends were provided with apertures through which broken stone, gravel, etc., could be introduced, by means of which the aggregate weight of the machine could be increased to twelve tons.

Steam Road-rollers.—Road-rollers propelled by steam-power have lately been used to some extent, and with satisfactory results. Figure 24 (*pl.* 20) exhibits a machine of this class built by Aveling and much used in England. This machine has two driving-rollers in front, one of which runs loose on its axle to enable the machine to turn short curves. The driving-axle is rotated by chain-gearing from the crank-shaft, and similar gearing is used for connecting the steering-wheel with the two large rollers at the rear. These are journaled in a turn-table, which may be rotated horizontally by the steering-wheel to guide the machine in any direction. The machines are of four sizes, weighing respectively fifteen, twenty, twenty-five, and thirty tons. In the heaviest, shown in the picture, the driving-rollers weigh six tons, have a diameter of 7 feet, and are 2½ feet long. They have a clear space between them of about 4½ feet. At the rear are two heavy rollers, placed close together. These are each 2½ feet long and act as a single roller of 5 feet, passing over that portion of the road which the front rollers leave untouched. The entire machine is self-contained within the frame, and its movements are readily controlled by the engine-driver. Its weight is so distributed that nineteen tons rest upon the front rollers and eleven upon the rear rollers.

Sweeping-machines.—Besides the common brooms and wooden scrapers, dust-sweepers like that seen in Figures 25 and 26 (*pl.* 20) are employed for street-sweeping. Figures 27 and 28 show a form of sweeper used upon the macadamized streets of Paris. This consists of a suitable framework or body mounted on wheels and drawn by horses. It carries at the rear end a cylindrical brush about 4½ feet long, having its axis placed obliquely to the axle of the wagon. As it moves along, therefore, it sweeps the mud from the middle of the street to one side, and a second machine, of the same kind, coming after the first, sweeps the stuff into the gutter. The brush is rotated by means of an endless chain driven by suitable gearing from the axle of the wagon, and by means of a lever may be lowered to the street surface and put in rotation, or thrown out of gear by raising it up when not required to sweep. One such machine, it is calculated, will do the work of thirteen men, and represents a saving over hand labor of about 50 per cent. The ridges of dirt left by the sweeper are removed in the usual manner with shovels and carts, or the operation may be assisted by the use of mud-scrapers of the pattern shown in Figure 29.

It may be interesting in this place to take notice of several more elaborate devices invented and used to some extent for the removal of street dust and mud. Figure 3 (*pl.* 21), for example, exhibits in section a street-sweeping machine in which a cylindrical brush is set in rotation by means of gearing from a spur-wheel on the driving-axle. The driving spur-wheels engage pinions turning loosely on the counter-shaft, but clutched thereto in such a manner as to allow of free rotation in one direction. The rotary brushes, which obtain their motion from this shaft through chain gearing, deposit the mud in the dumping-receiver, placed directly in front of them. Another form of machine is seen in Figure 4. In this, the street dirt is swept into a receiver by means of an endless belt set around with brushes and actuated by gearing from the driving-wheels. In American cities sweepers provided with one or several brushes set obliquely to the driving-axle and actuated therefrom are in common use for removing accumulations of snow and ice from the tracks of the street-railways. With these the snow is thrown up into ridges on one or both sides of the street.

Street-sprinklers.—To lay the dust in advance of the sweeper, various forms of street-sprinkling devices are used. One of these is shown in Figure 30 (*pl.* 20). This consists of a line of water-pipe connected with flexible hose-sections and provided with a suitable nozzle. The line is mounted on swivelling rollers, so that it is readily portable, and when required for use is connected with the city service-pipes, as seen in the sketch. On the streets and in the parks of American cities there are used, during the warm season, various forms of sprinkling-carts, from which the water is discharged in a spray, the flow being controlled by a valve operated by the driver; these carts are drawn by horses or mules.

2. VEHICLES.

Historical.—The term vehicle, in its widest application, embraces all structures employed for the purpose of transportation of merchandise and of human beings. Specifically, vehicles which are hung on springs and used for pleasure are termed *carriages.* Four-wheeled vehicles used for carrying goods and heavy loads are commonly called *wagons*, and two-wheeled vehicles without springs are *carts.* In ancient times the only vehicles were two-wheeled carts, called chariots, which were used both for pleasure-riding and in war. A Greek tradition attributes the origin of wheeled vehicles to Erechtheus, the first king of Athens, about 1400 B. C., but the first form of wheeled vehicle is known to have been in use as early as 2000 B. C.

Egyptian Vehicles.—We possess ample information as to the build and decoration of the chariots of the Egyptians from their sepulchral paintings. The Egyptian chariot, which was used in state processions, in warfare, and for racing, was constructed principally of wood, and rested on an axle, upon which the wheels were secured by linch-pins. Frequently the wheels were fixed to the axle, which turned with them. The chariots invariably had two wheels, which were secured at the junction of the fellies with clamps or bands of bronze, and bound with a tire of that metal.

Greek Vehicles.—The Greek chariot had an axle usually made of oak, ash, or elm, though Homer describes the chariots of Juno and Neptune as having metallic axles. The wheels of the Greek chariots were about 4 feet in diameter, and each consisted of a nave (bound with an iron ring), spokes, fellies of elastic wood, and a heavy iron tire, and were fastened to the axle by pins.

Roman Vehicles.—The Roman triumphal chariots, which were usually of ivory, adorned with the utmost skill, and drawn by a number of white horses, were the chief features in the processional celebrations. In the Roman games chariots were often decorated with sculptures enriched with gold and ivory. The Romans had one-wheeled vehicles, which were drawn by slaves, and also vehicles with two and four wheels. They had carriages adapted for two, three, and four horses, and it was among the Romans that the use of carriages as a private means of conveyance was first established, and their carriages attained a great variety of form and richness in ornamentation. Because of the narrowness of the roads and the crowded condition of the streets in Rome, carriage-travel was restricted to a few persons of high rank. For making long journeys and conveying large parties, the *rœda* and *carruca* were mostly used, but their construction and arrangement are unknown. The *carrucæ*, which are said to have been gorgeously trimmed, had no springs. During the Empire, the carriage which appears in representations of public ceremonials is the *carpentum*, a very slight vehicle with two wheels, sometimes covered, and generally drawn by two horses. The *sirpea*, which originated with the Gauls, by whom it was called *benna*, was an ancient form of vehicle employed for the conveyance of persons and goods. The body of this vehicle was of osier basket-work. The *essedum* was a two-wheeled carriage, whose form the Romans copied from the war-cars of the Belgæ. The *arcena* was a covered carriage for the use of the sick and the infirm. Covered carriages become more and more the appendages of Roman pomp and magnificence, and sumptuary laws were enacted on account of the public extravagance, but these were little regarded, and were entirely abrogated by the emperor Severus. With the fall of Rome, carriages fell into disuse.

French Vehicles.—Carriages were in use in France to a limited extent at a very early day, but for a time they were restricted to the sick, to royalty, and to ambassadors. Philip the Fair, in 1294, issued an edict by which the wives of the citizens were forbidden to use them. At Paris, in the fourteenth, fifteenth, and sixteenth centuries, the French monarchs rode on horses and the servants on mules. Carriages did not grow in favor very rapidly, and we find that in 1550 there were only three in Paris—one belonging to the queen, one to Diana of Poictiers, and the third to René de Laval.

German Vehicles.—In 1474, Emperor Frederick III. visited Frankfort in a close carriage, and again in the following year in a magnificent covered carriage. Shortly afterward carriages began to be splendidly decorated. At the tournament held at Ruppin in 1509 the carriage of the Electress of Brandenburg was gilded all over, that of the Duchess of Mecklenburg was hung with red satin, and the carriages of twelve other ladies of rank were elaborately lined and ornamented. The wedding-carriage of the Emperor Leopold's first wife, who was a Spanish princess, cost, together with the harness, three thousand eight hundred florins. The carriages of the emperor are described as of no great magnificence; they were covered with red cloth fastened with black nails, and the whole work was without gilding. The panels of the carriages were of glass, and for this reason they were called the imperial glass coaches. These were distinguished only by having leather traces, but the ladies in the imperial suite were obliged to be contented with carriages having traces of ropes. The harness was black, but on festival occasions it was ornamented with fringes of red silk.

English Vehicles.—The introduction of coaches into England took place during the sixteenth century, and has been credited to Sir Thomas Chamberlayne, who was ambassador to the courts of Charles V., Philip II. of Spain, and the king of Sweden. The oldest carriages used in England were known as chares, cars, chariots, carrouches, and whirlicotes. The earliest English coaches are described as consisting of a body covered by canopies, which were supported by pillars and surrounded by curtains of cloth or leather, which could be folded up when desired. The coaches were without springs, and were driven by a postilion, who rode the near wheel-horse. The driver's seat was added at a later date. Glass windows are said to have been first used in 1631 in the carriage of Mary, queen of Spain. The best-known English coaches possessing a history are Her Majesty's state-coach and that of the lord mayor of London. The latter is the older, having first been used in 1757 for the procession of Sir Charles Asgil, lord mayor elect. The body of this remarkable vehicle was not supported by springs, but hung on heavy leather straps, and the vehicle was richly ornamented with carving, painting, and gilding. The royal state coach, described as "the most superb carriage ever built," was designed by Sir William Chambers, the paintings on it were executed by Cipriani, and the work was completed in 1761. The entire carriage was beautifully adorned with carved work and gilding. It was 24 feet in length, 8¼ feet in width, 12 feet in height, and weighed four tons. Enormous sums were lavished upon the carriages of the wealthy and high-born in the sixteenth and seventeenth centuries. A state coach built in Italy in 1629 for the marriage of Edward Farnese and Margarita of Tuscany was resplendent with two thousand five hundred ounces of silver, and it required the work of twenty-five silversmiths and two years' time for its fabrication. In Italy artists of note were employed to paint the panels of the coaches, and in 1516 Pontormo painted two triumphal cars for Leo X. Figure 8 (*pl.* 21) exhibits an English coach of the seventeenth century.

Construction of Vehicles: Running-gear.—The construction of the vehicle is quite as important in reference to the amount of load to be transported as is the nature of the road. In pleasure-carriages carrying capacity is of secondary importance, the principal object being to secure personal comfort, lightness, and elegance. For convenience, all road-vehicles may be classed as two-wheeled and four-wheeled. From the constructive standpoint, each consists of an under framework (comprising what is commonly called the running-gear) and an upper framework, or the wagon-body. It will suffice for the scope of this work to consider briefly the construction of the running-gear only. The most important part of the running-gear consists of the wheels and their axles. The wheels are made up of the hub, the spokes, and the rim (*pl.* 20, *figs.* 36, 37). The hub consists of a solid block of wood (in rare cases of cast iron) strengthened on the outside with bands or rings of wrought iron, a cast-iron or brass box being let into the centre to serve as a bearing for the axle, which passes through it. A recess is provided to hold a quantity of grease for lubrication. The perimeter of the wheel is formed of two or more annular segments of wood firmly united by dowel-pins. When only two of these segments are used, they are called half-rims; when more than two segments are used in the rim, they are called fellies. The half-rims, or fellies, are held firmly together by a circular wrought-iron band called the tire. This is expanded by heating, then shrunk on, so as tightly to compress the wheel, and bolted. According to Knight, the circular continuous tire is of American origin, the practice in Europe, until lately, being to make the tire in sections arranged so as to break joints with the fellies. The spokes, usually made of oak (or, for the lighter class of vehicles, of hickory), are radial arms which connect the hub with the rim of the wheel. The foot-tenon of each spoke is inserted into a mortise formed in the hub to receive it, and the rim-tenon is similarly inserted in the rim or felly. There are commonly two spokes to each felly.

In heavy vehicles the wheels are not set perpendicularly to the axis of the hub, but in such a manner as to incline outwardly, as seen in Figure 35 (*pl.* 20), giving them what is technically called "dish." In connection with this it is found necessary to give a slight downward inclination to the axle, varying in degree to correspond with the amount of dish given to the wheel (*fig.* 35). In the case of light vehicles the spokes are set straight in the hub, but receive dish by the shrinking on of the tire. This artifice is claimed to afford the following advantages—namely, it provides increased space for the wagon-body, the mud and dirt are more readily thrown off and away from the wagon, and a certain elasticity and lateral stiffness are obtained, and, where the roadway is strongly arched, better contact between roadway and tire is assured.

It is customary to make the bearing portion of the axle slightly tapering, and (at least in American practice) the axle-box is adjusted as snugly as possible, especially with the lighter class of vehicles. The axle, made of wrought iron or steel, is given a square section between the bearing-ends, and is secured by means of clips to the axle-bed (*fig.* 34). In the case of carts this axle-bed serves as a carrier of the wagon-body as well as for the attachment of the shafts (*pl.* 24, *fig.* 9*a*).

The running-gear of a four-wheeled wagon comprises a front and back carriage part, usually joined together by the perch. Figure 32 (*pl.* 20) exhibits a side view of a heavy wagon with the wagon-body removed; Figure 33 is a half ground-plan of the same; Figure 34 exhibits half of the front running-gear; and Figure 35, the same of the back. The axle-bed of the front part, as shown in the illustration, is connected by iron bands with the woodwork immediately above it, forming a species of truck through which the futchels pass for receiving the pole, and to which the pole is firmly fastened. A suitable slot is provided in the fore truck for the attachment of the front end of the perch, which likewise is firmly secured to the hind truck. The wagon-body, of which only the two horizontal supporting beams are shown in the figure, rests, with these, directly upon the hind-truck; in front, however, the supporting beams are joined to a cross-piece

—the transom—which, in turn, is supported upon the truck of the fore axle. This transom is connected with the truck and with the front end of the perch by the kingbolt, which is passed through them, forming a pivot. It is plain that by this artifice the wagon may be turned about with great ease, since it permits of considerable lateral deflection of the front axle with its truck independently of the wagon-body.

The above-described construction is now very generally modified by dispensing with the perch. Figure 38 (*pl.* 20), for example, represents an English farm-wagon of this description, in which the front wheels are carried entirely under the wagon-body. It admits of being moved and turned about with great ease.

Upon pleasure-vehicles the omission of the perch is quite common, and has certain advantages: it permits the body of the vehicle to be set lower, thus facilitating getting in and out, and, by lowering the centre of gravity, makes the structure more stable. Much attention has also been bestowed on the construction of the axle-box, and numerous patented inventions have been introduced having for their object the attainment of greater security against the coming off of the wheels when driven at high speed, and the protection of the axle against rapid wear and cutting by more or less effective methods of excluding dirt and grit.

Classes of Carriages.—The variety of pleasure-carriages is legion, and the names by which they are distinguished are often quite arbitrary. The more recent models embrace the vehicles called, respectively, the landau, Berlin coach, English coach, extension-front brougham (*pl.* 21, *fig.* 9), coupé, landaulette (*fig.* 12), wagonette, calash, phaëton (*fig.* 15), buggy (*fig.* 11), Whitechapel, dog-cart, cabriolet (*fig.* 13), surrey (*fig.* 14), rockaway (*fig.* 10), T-cart, and numerous others.

Public Conveyances for the transportation of passengers and mail fall in this category. As early as the beginning of the seventeenth century the English had instituted a systematic public service of coaches for the transportation of passengers between the principal cities, and the stage-coach has reached its highest state of perfection in that country. In France they had for the same purpose, first the slow "diligence," then the "malle-poste," and the coaches of the "Messageries Royales" and "Lafitte." In Germany it appears that passenger-posts were first introduced after the Thirty Years' War, and the "Eilwagen," which came into use at the beginning of the present century, appears to have been modelled after the practice of the French.

Hackney-coaches—so called from the French *coche-à-haquenée;* that is, a coach and horse let out for hire for short journeys—were first brought into use in France during the seventeenth century by one Nicolas Sauvage, who lived at the sign of "St. Fiacre," in the Rue St. Martin, and hence hired carriages came to be called *fiacres*, though eventually the name was restricted to such as were stationed in the streets. Hackney-coaches were first established in London in 1625. The *cabriolet de place*—now shortened into "cab"—came into popular favor in France about the middle of the eighteenth century. The original *cabriolet* was a kind of gig, inside of which sat the driver, beside whom there was room left for only a single passenger. Hansom, the inventor whose name is attached to the London two-wheeled vehicle of the present day, patented his cab in 1834. It consisted originally of a square body hung in the centre of a square frame, the two wheels being about 7½ feet in diameter, the same height as the vehicle. The prototype of the modern omnibus first commenced plying in the streets of Paris in 1662, going at fixed hours and at a stated fare. Soldiers, pages, and livery-servants were forbidden to enter such conveyances.

In what is now the United States common-carrier lines for transporting goods and passengers were in existence in the early part of the last century. The special attraction of a line of passenger-coaches established in 1766 to run between New York City and Philadelphia was that it had "good stage-wagons with the seats set on springs." The following data respecting American progress are collated from the rich fund of information on the history of transportation collected by Luther Ringwalt. Before the present century very few steel carriage-springs were used in the United States. A favorite method of guarding passengers against the jolting and jarring on rude roads was to hang the bodies of the coaches on strong leather supports, which, in turn, were sometimes supported by a simple form of steel spring, and this plan continued to be used extensively during part of the present century. The "tally-ho" coach, or drag—sometimes called four-in-hand because drawn by four horses—is an importation from England. It is a large vehicle built somewhat like a stage-coach, with seats inside and outside. This kind of conveyance is much used by gentlemen-drivers who wish to carry large parties on the road for pleasure.

Wagon-springs.—The introduction of springs for supporting the wagon-body and its load, in place of resting this directly upon the axles, represents a great advance in construction. At first these devices were applied only to the class of vehicles called pleasure-carriages, but of late years they have come to be almost universally employed, not only upon carriages and public conveyances for passenger service, but also upon farm-wagons and those intended for the transport of merchandise in cities and towns, from the delivery-wagon of the grocer and baker to the heaviest wagons of the brewers and of the freight and express companies, capable of carrying a load of several tons (*pl.* 21, *figs.* 5, 6).

The advantage to be derived from the use of springs upon vehicles intended to transport heavy loads was well known many years before their adoption upon such vehicles became general. At present almost all wagons used for this form of service (light and heavy freight-wagons) in American cities are provided with springs, and by their use a great gain is effected in rapidity of travel, in the weight that a horse (or a number of horses) can draw, and in the saving of the wear and tear of wagons and streets. A large proportion of the light freight-vehicles used in country districts are also furnished with springs.

In pleasure-vehicles and others in which springs are introduced (*pl.* 20, *fig.* 39) this feature involves, likewise, certain subordinate modifications of the mechanical structure. As the pressure of the carriage-body and its load does not come directly upon the axles, but indirectly through the interposed spring or springs, the effect of the irregularity of the road-surface, which would otherwise be transmitted from the wheels to the axle and from this to the wagon-body as a succession of jolting and jarring blows, is modified by the springs into a gentle vibratory movement in a vertical plane. The spring (*fig.* 40), therefore, not only renders driving over the roughest roads, if not positively comfortable, at least endurable, but also lowers the tractive force required to transport a given load and notably diminishes the wear and tear of the vehicle. The front truck of spring-vehicles turns upon a kingbolt, as in the case of the springless wagon above described. For accurate guiding, the so-called "fifth wheel," which is fastened to the futchels and to the axle-bed, is now commonly used in all forms of wagons.

Ringwalt further notes that few of the minor industries have increased (in the United States) more rapidly than the manufacture of carriage- and wagon-springs, on account of the immense increase in the number of vehicles used and the cheapening of steel through the Bessemer and open-hearth processes. They are now made in great variety, of which it will be unnecessary to give the specific names. Some of the forms in common use upon freight-wagons are shown on Plate 21 (*fig.* 7*a–c*).

Wagon-building.—Great advances are noted by Ringwalt in connection with the materials and shapes of various parts of carriages; in the adoption of contrivances for preventing the escape of lubricants; in substituting iron for wood in parts of vehicles where great strength is demanded; in improving the construction of axles and wheels; in the mode of fastening the spokes; in increasing the facilities for turning within a short space; in designing special forms of vehicles for special service; in decreasing the weight of many classes of vehicles; and, generally, in all the details of their construction.

In the aggregate these improvements have greatly added to the utility of wheeled vehicles, and their introduction of late years has enormously increased. To what extent this has been the case may be judged from the statement made at a recent convention of the Carriage-builders' National Association, that in the State of Ohio alone there are built each year more pleasure-carriages than are built in England, Scotland, Ireland, France, and Germany combined. The value of the carriages and wagons manufactured and sold in the United States, annually, was estimated some years ago at one hundred million dollars.

Arrangement and Size of Wheels.—From the technical description which has been given in what has preceded, it is evident that to preserve the wagon-body in a horizontal position the front wheels must be lower than the rear ones. This arrangement not only contributes to the ease of motion of the vehicle, but also permits of the attachment of the traces in a more advantageous position. The size of the wheels of vehicles is of importance. This element varies greatly according to the use for which the wagon is intended. Thus, for rapid vehicles, the diameter of the front wheels may be from $2\frac{3}{4}$ to 3 feet, and that of the hind wheels from 4 to $4\frac{1}{2}$ feet; on heavy freight-wagons, on the other hand, it may be, for front and hind wheels, from 3 to $3\frac{1}{2}$ feet and from $5\frac{3}{4}$ to $6\frac{1}{2}$ feet, respectively. The poorer the road, other things being equal, the larger should be the wheels, since experiment has demonstrated that for a given load the required tractive force on broken-stone roads and paved streets is approximately inversely proportioned to the radius of the wheel.

The Wheel in Relation to the Load.—Since the pressure of a wheel upon the road diminishes proportionately with the increase in the width of its felly, and since this pressure must not exceed a certain maximum, lest the road be utterly ruined, laws have been enacted in different countries defining the minimum permissible width of felly for different wheel-loads. By the rule established by the experiments of Morin and Dupoint, 275 pounds of load may be allowed for each $\frac{2}{5}$ inch of width of felly, and, as extreme limits for the latter, from $2\frac{1}{2}$ to $4\frac{3}{4}$ inches. Respecting the weights of the vehicles themselves there are the widest variations, the extreme range being from ninety-five pounds in the lightest pleasure-carriage to five tons for the heaviest freight-wagons.

Tractive Force.—The resistance to be overcome by a moving wagon will depend on its construction, the condition of the road, and the rate of speed, and it will vary between very wide limits. According to Bockelberg, the coefficient of resistance—namely, the ratio of the tractive force to the total weight to be moved—may be assumed to be, on stone roads, $\frac{1}{25}$ to $\frac{1}{75}$, and on earth roads from $\frac{1}{5}$ to $\frac{1}{20}$.

Animal Power.—The drawing-power of the draft animals by which the resistance above-named must be overcome will depend on their race, build, bodily condition as regards nourishment, and weight. On the average the tractive force that will be exerted by an animal motor may be taken at one-fourth its weight, so that for freight-wagons heavy horses must be chosen. With one and the same animal, the tractive force exerted, the time in which the work is done, and the speed with which the load is moved are related to one another, so that an alteration of the value of one of these factors implies the alteration of the other two, unless the animal be overworked. Thus, under normal conditions, an animal must put forth only so much power during a given time at a given speed. If it is required to put forth more power than this, then it must be either at a lower rate of speed or for a shorter time. Furthermore, each animal has a normal gait or rate of speed, to maintain which he will require neither to be driven nor held back. These data have been carefully worked out and mathematically expressed by Maschek. The effective work of a horse may be stated in the following terms: The average load which a single horse can draw at the rate of twenty miles per day (of ten hours) in a cart or wagon weighing 7 cwt. is 1800 pounds.

Harnessing.—Furthermore, the mode of harnessing has a decided influence upon the work the animal is able to perform. In the case of pleasure-carriages and the like, which commonly run upon good roads and depend largely for their progress upon the freedom of movement of the horse, the traces are attached in a horizontal position; *per contra*, in the case of heavy vehicles and upon bad roads, an inclination of the traces is found decidedly advantageous, for not only will this disposition enable the horse to obtain a better purchase against the ground in pulling the load, but the wagon will be more easily lifted out of the ruts in the track. The average inclination for the traces may be taken at 10°.

Grades.—Upon steep gradients the moving of the load becomes more difficult, for the obvious reason that the animal must partly raise his own weight in addition to that of the load. To offset this extra strain upon the horse, his speed must be lessened. It follows as a matter of course that the greater the height to be scaled, the more gentle should be the grade of the road. The best road, other things being equal, is that which has the smallest number of steep grades; for on such a road the maximum burden that may be moved on other sections will not be interfered with, since there will be no necessity to call into service the work of extra horses, which otherwise would be found necessary. The maximum grade for stone roadways may be assumed at 1 : 24, although for roads in mountainous regions this rule will not hold good.

Summary.—From all that has preceded it will be evident that in laying out a road the selection should be made of that line which is the shortest, which shall require the fewest steep grades, and which shall be so situated as to afford the best opportunity of keeping it in repair. It may not always be possible to choose the line which presents the greatest advantages from a technical point of view, in which case the rule will be modified by the pressure of circumstances.

The subject of roadways leads in natural sequence to that of railways, which will be considered in the following section.

II. RAILROADS.

A. HISTORY OF RAILROADS AND LOCOMOTIVES.

The railroad—which, thanks to the application of steam as the propelling power, has become the system by which the principal part of the internal traffic of the civilized nations of the world is carried on—has developed to its present state from ancient and very crude practices. The first step in this direction seems to have been to provide a hard and smooth surface over which heavy bodies could be moved with economy of power. There is reason to believe that the stones used in the building of the pyramids and temples of ancient Egypt were brought from the quarries upon causeways formed of large hewn stones over which rollers bearing great blocks weighing many tons were made to pass. The Romans employed blocks of stone to form a way upon which heavy burdens could be drawn with greater ease than upon common roads, and a similar practice appears to have been followed by other peoples of Europe.

Early Tramways.—Some three hundred years ago, in the mines of the Harz Mountains, in Germany, and somewhat later in the English coal-mines, wooden tracks were introduced upon which the coal- and ore-wagons were drawn. The first road of this kind is known to have been laid down in 1602 at Newcastle, and from this date onward, roads provided with tracks of one kind or another gradually found their way throughout the mining districts of England, Scotland, and Wales, and from time to time their construction was improved. Toward the close of the seventeenth century they had come into general use, and a century later the utility and economy of such "tramways," as they were called, had become so well recognized that considerable sums were expended upon their construction, the inequalities of the ground being overcome by cutting and filling, as is done to-day in order to bring the roads to a uniform grade.

The Rail.—The development of the rail proceeded from the crude timber way above spoken of until eventually it came to be made of iron. At first this was merely a thin strip of wrought iron or a moulding of cast iron, to protect the wooden rails from rapid wear. In 1776, a tramway was laid at Sheffield having cast-iron rails with an upright flange, spiked down to longitudinal sleepers of timber (*pl.* 22, *fig.* 4). The cast-iron edge-rail of Jessop, introduced in 1789, was the first approximation to modern methods of construction. This rail was of oval section, and in connection therewith a chair was used—a block of iron slotted to receive the ends of adjacent rails (*fig.* 5). The wheels of the wagons were made with flanges to keep them on the rail, in the manner of those now employed. Since 1830, the T-rail has come into general use. Wrought-iron rails were first rolled by Birkenshaw in England about the year 1820. The first steel rail was rolled in 1857 by Mushet at the Ebbw-Vale Iron Company's works, in South Wales, and at the present time Bessemer steel has almost completely supplanted iron for this purpose. The rails are made from 15 to 30 feet in length, and, according to the severity of the traffic they are to withstand, have a weight of from forty-five to one hundred pounds to the yard.

For drawing the comparatively light loads on the primitive railways, men or horses were employed, or in the case of steep ascents a loaded train, descending, was made to haul up an empty one by means of cables or bands passing over fixed rollers. More rarely stationary steam-engines were used.

First Application of Steam to Locomotion.—The successful application of the steam-engine to locomotion was not actually accomplished until well into the present century. In 1769, Watt, in England, patented the use of steam-engines for running carriages on land, but there is no evidence that he ever attempted a practical application of the idea. The first actual experiment with a steam-carriage (*fig.* 1) of which there is authentic record was made by a French army-officer, Nicholas Joseph Cugnot. It was intended for the transportation of artillery. It consisted of two heavy beams of timber extending from end to end. Two heavy wheels were placed at the rear of the structure, and one heavier but smaller driving-wheel in front. The steam-boiler was of copper, and was fashioned much like a common kettle; the driving-wheel was actuated by two single-acting engines, one on each side of it, having steam-cylinders 13 inches in diameter. This engine is preserved in the Museum of the Conservatoire des Arts et Métiers, in Paris. From Thurston's account, the carriage and its machinery are substantially built and well finished, and in respect of workmanship are exceedingly creditable.

Oliver Evans' Steam-dredge.—In America the idea of applying steam to locomotion was seriously proposed by Oliver Evans, who is generally credited with the invention and introduction of the first successful high-pressure steam-engine. His application to the Legislature of Pennsylvania in 1786 for a patent covering the adaptation of the steam-engine to driving mills and to the steam-carriage, was refused, but in the following year a similar application to the State of Maryland was granted. In 1801, he built a steam dredging-machine on an order from the authorities of the city of Philadelphia. This he fitted with wheels connected with the engine, and, though it was set upon wooden axles, he conveyed it through the streets of the city, a distance of a mile and a half, to the place of launching, in the river Schuylkill. A picture of this historic craft is shown on Plate 22 (*fig.* 2).

Trevithick's First Locomotive.—The first practical locomotive to run on rails or trams was built by Trevithick and Vivian for a railroad at Pen-y-darran, in Wales. This was in the year 1804. The engine was of the high-pressure, non-condensing type, and exhausted into the chimney. On its trial-trip it drew a load of ten tons at the rate of five miles an hour. A picture of this machine is shown in Figure 3. It has been asserted that Trevithick's engine had cog-wheels and ran on a rack-rail, but there is abundance of evidence showing that this was not the case. An eye-witness, in describing its performance, says, "Lightly loaded, it did very well upon a level surface or moderate grade, but, more severely tasked, the wheels would *slip round* without advancing." In his knowledge of the fact that sufficient traction could be obtained from the adhesion of a smooth-surface wheel upon a smooth rail, Trevithick appears to have seen more clearly than others who succeeded him.

Blenkinsop's Locomotive.—For a number of years after this partially-successful experiment the attention of inventors in their efforts to improve upon Trevithick's engine was directed toward overcoming an imaginary difficulty—namely, that the friction of smooth wheels upon a smooth track would not afford traction sufficient to haul loads of considerable weight. Blenkinsop, for example, in 1811, built a locomotive for the Middleton colliery which was provided with spur-wheels working into a toothed rail or rack on one side of the track. This system was in service for a number of years on a colliery railway between Leeds and Middletown, a distance of three and one-half miles, over which it is reported to have hauled trains of thirty tons' weight at the rate of three and three-quarter miles an hour (*pl.* 22, *fig.* 6).

Hedley's Locomotives.—About this time, also, Hedley built an eight-wheeled locomotive, the wheels of which were driven by gearing to obtain increased tractive adhesion.

"*Puffing Billy.*"—Hedley, in 1812, seems to have been the first to realize the significance of the early experiment of Trevithick with smooth wheels on a smooth track. In that year he built an experimental carriage the wheels of which were turned by men stationed at four handles. This he attached to trains of coal-wagons, and, weighting it with varying weights, and at the same time varying the load to be hauled, he determined by repeated experiments that by the proper proportioning of the weight upon the driving-wheels to that of the load sufficient tractive adhesion could be obtained upon a smooth rail without the auxiliaries of spur-wheels and racks. Having determined this important fact, he proceeded in 1813 to build a locomotive to haul the coal-trains at the Wylam colliery. This engine had four smooth driving-wheels adapted to a smooth rail. Its boiler-power was found to be inadequate, and this defect was corrected in a second and larger one. This engine had a wrought-iron return-flue boiler, and had eight driving-wheels coupled together by intermediate gear-wheels on the axles, and all propelled by a gear at the centre, which was driven from a walking-beam by the intervention of a connecting-rod and crank. This engine hauled eight loaded coal-wagons at the rate of ten miles an hour. The exhaust was led into the chimney, and the opening of the exhaust-pipe, the end of which was turned upward, was contracted, by which means the blast was intensified. "Puffing Billy" (*pl.* 22, *fig.* 7), as Hedley's locomotive was called, continued in use at the Wylam colliery for many years. In 1862 it was removed to the British Patent-Office Museum, in London, where it is preserved as a memorial.

Brunton's Locomotive.—Among other constructions remarkable to-day as curiosities was a locomotive devised by Brunton which was propelled by two jointed rods or movable legs, in imitation of the action of the hind legs of the horse.

Stephenson's Locomotives.—George Stephenson built for the Stockton and Darlington road three locomotives which on trial exhibited considerably greater merit than any that had hitherto been designed. They weighed about eight tons each. The boiler was provided with a single straight flue. The cylinders of the engine were vertical, and were coupled directly to the driving-wheels. They had two pairs of drivers coupled by horizontal rods; they used a forced draught. At the trial of the "No. 1" engine of this type (*pl.* 23, *fig.* 3) on the opening-day it drew ninety tons at the rate of twelve miles (and at times fifteen miles) an hour.

First Railroad.—The history of the modern railroad system, however, may be said to date from 1829, when the first railroad built for general traffic and travel was completed. Down to the year 1825 all the railroads that had been built were employed exclusively for the transportation of coal and similar crude products of the mine, furnace, and quarry. In that year the Stockton and Darlington Railroad—projected for the purpose of securing transportation to tide-water for the output of the valuable coal-fields of Durham—was opened. On this road the experiment of transporting passengers and goods was first attempted. It is curious to note that the passenger-coaches were for some time drawn by horses. Mixed passenger- and freight-trains were next introduced upon the line, and later special passenger-trains; and the new method of transportation became popular and profitable to the company. The want of confidence felt in the new method of transportation so far as it applied to passenger traffic is exhibited in the curious illustration (*pl.* 23, *fig.* 3), which represents a man on horseback, who, until the engine developed a dangerous rate of speed, marched in front of the first train of the Stockton and Darlington road.

Opening of the Manchester and Liverpool Railroad.—In 1829 the first railroad designed and built for general traffic and travel—the Manchester and Liverpool Railroad (*figs.* 1, 2)—was completed, and it is a matter of record that the consent of the directors "to give the travelling engine a chance" was obtained only after the most persistent effort. Some of them favored the use of horses; others advocated the stationary hauling-engine; and even the experimental demonstration of the practical value of the locomotive engine on the Stockton and Darlington road failed to impress them. Finally, they were persuaded to offer a reward of five hundred pounds for the best locomotive engine, the principal conditions prescribed being that it must be able to draw on a level three times its own weight at a speed of ten miles an hour. The wide publicity given to this announcement stimulated a number of engine-builders to compete for the reward. Only three locomotives were finally entered for the trial, which took place on the 6th of October, 1829. These were the "Novelty," built by Braithwaite and Ericsson; the "Rocket," built from the plans of George Stephenson; and the "Sanspareil," built by Timothy Hackworth.

The Rocket (*pl.* 22, *fig.* 9) proved successful over its rivals, though, considering the time and the circumstances, the performance of all the engines was very remarkable. The Rocket, carrying a tender with water and coke (three tons four cwt.) and two loaded wagons (nine tons ten cwt.), attained a maximum speed of twenty-four and one-sixth miles an hour, with an average consumption of two hundred and seventeen pounds of coke per hour. The Novelty attained a maximum speed of twenty-eight miles an hour, but, in consequence of the repeated failure of its blowing apparatus, was withdrawn. The Sanspareil made twenty-two and two-thirds miles an hour, but its fuel-consumption (six hundred and ninety-two pounds per hour) was excessively high.

The success of the Rocket was doubtless due in large measure to the high efficiency of its boiler, which was of the so-called "multitubular" type, by which form of construction a large increase of heating surface, with consequent rapid steaming-power, is obtained. It was provided, also, with the steam-blast in the chimney. These early trials fully established the value of the multitubular boiler over all others for locomotives, and also the great advantage of the steam-blast; and these important elements of construction have retained their pre-eminence to the present time. This engine continued in service on the Liverpool and Manchester road until 1837, when it was withdrawn. After several years of inglorious service in the collieries it was finally placed in honorable retirement in the patent-museum at South Kensington, London, where it is now preserved as a relic of historic interest.

The fame of these remarkable performances, so far in advance of all anticipations, spread rapidly throughout the world, and the railway era, which has wrought so profound a revolution in the system of transportation, and has so prodigiously stimulated the activities of modern life, was ushered into existence.

It will be interesting at this point to devote some attention to the pioneering work that was being done in the introduction of the railroad in other countries.

Early Railroads in France.—In France, Seguin is credited with having begun in 1826 the construction of a railroad running from Roanne (*via* St. Etienne) to Lyons, on which locomotives were placed in service in 1832; but it appears that railroads for general traffic were not introduced in that country until the year 1839, nearly ten years after the opening of the Manchester and Liverpool road.

Early Railroads in Belgium and Germany.—Belgium is credited with being the first of the nations of Continental Europe to develop a system of railways, the moving spirit in the work having been Pierre Simon, who, in conformity with a government decree issued July, 1834, prepared comprehensive plans for railroad communication throughout the kingdom. These plans were promptly approved, and the Brussels and Mechlin Railroad was opened for traffic on the 6th of May, 1837. In Germany, about the same time, the first general-traffic steam-railroad was built by Denis. It ran between Nuremberg and Fürth.

Early Railroads in the United States.—In the United States, where the subject of providing means of internal communication at this time was an absorbing question, the success of the Liverpool and Manchester experiments attracted profound attention. Crude tramways had already been introduced. In 1809, Thomas Leiper of Philadelphia had constructed and operated what is believed to have been the first railroad in the United States. It was used for the transportation of stone from his quarries on Crum Creek to his landing on Ridley Creek, a distance of about one mile. The Quincy Railroad, which is often quoted as the first railroad in America, was not completed and operated until 1827. This was four miles long, and ran from a granite-quarry to the port of Neponset, in Massachusetts. Another and more extensive one, nine miles in length, was built in the same year from the coal-mines at Mauch Chunk, in Pennsylvania, to the Lehigh River. The first two of these roads were operated by horse-power, and the last by means of inclined planes with stationary engines and gravity. In the following year (1828) a number of important railroads were projected. The Delaware and Hudson Canal Company built a railroad in that year from its mines to the canal at Honesdale, in Pennsylvania, and the Baltimore and Ohio and Charleston and Hamburg Railroads were commenced.

Early Locomotives in the United States.—The first locomotive engine put to service in America was on the Delaware and Hudson Canal Company's line at Honesdale. This was the English-built "Stourbridge Lion." This engine was tried on the road in August, 1829, but was found to be too heavy for the roadway, and was shortly retired; it appears never to have been put to regular service. The Charleston and Hamburg Railroad placed the first American-built locomotive in service on its road in 1830. This was the "Best Friend" (*pl.* 22, *fig.* 8), and was built at the West Point Foundry, at Cold Spring, New York. It was succeeded early in the following year by the "West Point," of the same builders (*fig.* 10). Both of these locomotives are said to have done good service. In this year, also, the Baltimore and Ohio Railroad was equipped with its first locomotive, the "York," of American build. In Figure 11 is shown the so-called "Grasshopper" locomotive, a peculiar American type of engine, of which a number were built and operated for many years on the Baltimore and Ohio Railroad. From this time onward the development of the railroad in the United States progressed rapidly. Figures 5 and 6 (*pl.* 23) are pictures of early American passenger-railway trains.

The conditions prevailing in the United States are so different in many respects from those obtaining in European countries—as, for example, in the comparative newness of the country, in the very unequal distribution of the population, and in the great distances to be traversed—that the American system of railroad construction and operation differs in several interesting and important features from the European. Some of the more notable of these differences will appear farther on.

Growth of Railroad Systems.—From such beginnings has grown up the wonderful system of transportation which at the present day covers almost every portion of the earth with a network of rails, and which has wrought more radical changes in the social and industrial order than any other single cause. With the rapid growth of the railroad, inventive ingenuity has wonderfully improved and rendered more effective every detail of its service. The ever-increasing demands upon the speed and power of the locomotive have culminated to-day in the luxuriously-appointed express-train, transporting its passengers at the rate of fifty miles an hour, and the Rocket, weighing less than five tons and drawing a weight of fifteen tons, has given place to the fifty-ton freight-engine drawing after it the enormous burden of nearly seven hundred tons. To what extent the railroad systems of the world have grown may be seen from the following table, which exhibits the mileage constructed and operated down to the end of the year 1884, the latest period for which reliable data are accessible, and which is given on the authority of Poor's *Manual of Railroads*—namely:

	Miles.		Miles.
Germany	22,814	United States	151,066
Great Britain	18,852	Canada	9,572
France	19,244	Other Countries of America, total	14,638
Other Countries of Europe, total	56,958	Total America	175,276
Total Europe	117,868	Asia, total	12,897
Australia, total	7,540	Africa, total	4,179
		Grand total	317,760

B. RAILROAD CONSTRUCTION.

1. Laying Out a Railroad.

The work of planning and laying out a railroad is something more than merely technical, since the question of the money that may safely be expended upon it, and consequently the character of its construction and operation, must be determined by the amount of traffic to be expected. The estimation of the probable passenger and freight traffic over a projected road is one of the most difficult of problems, demanding the closest inquiry into, and consideration of, the existing local and through traffic of the district, as well as the judicious valuation of the increased traffic which the new road may be expected to develop.

Classification of Railroad Traffic.—In the first place, the kind of traffic for which the road is designed to serve is the most important thing to consider in planning it, and from this standpoint the following classification may be made: (1) Roads for the transportation of materials such as are used in mines, quarries, in the construction of public works, and the like: these are often provisional or temporary, and are commonly operated by horses or men; (2) Surface railroads in cities, designed for passenger traffic: these rarely employ the locomotive, the low speed and frequent stops required and the occurrence of abrupt curves on such roads rendering the application of steam-power unsuited for this service, even were it not objectionable for other substantial reasons; and (3) Elevated, depressed, and underground roads, operated by steam, for the rapid transfer of the population of large cities: these roads are met with on both sides of the Atlantic. For the surface roads the electric motor and the cable-traction system have lately come into general use in American cities as a substitute for animal traction.

Freight and Passenger Traffic.—The objects which the steam-railroad proper is intended to realize are the transporting of passengers with the greatest speed compatible with safety and the transporting of freight with the lowest possible cost. Up to the present time the division of these two classes of traffic has been made chiefly by separating the same in different trains (passenger and freight); upon many of the principal railroads, however, the separation of passenger and freight service is effected by the laying of additional tracks, of which certain lines are used exclusively for freight- and others for passenger-trains.

Main (Trunk) and Branch Lines.—The route of the main lines of railroads will be determined by circumstances—for example, whether they are contemplated for countries with well-developed traffic and as the main stems or trunk-lines of a network of railroads covering the whole country, or whether they are contemplated for new or comparatively thinly-settled districts for the purpose of promoting the increase of their population and the development of their natural resources. While in the latter case the lines will be directed to those parts of the region whose products, etc. promise the most profitable returns, in the former the trunk-lines will be so located as to form the most direct connection between the important centres. Subordinate to the trunk-lines are those which may be designated as main lines of the second order, which serve as feeders to the trunk and as the means of supplying the industrial and commercial wants of localities of less importance; and subordinate to these, in turn, are the so-called branch or local roads, designed to transport and develop the local traffic of the districts contiguous to the main lines of the second order. The traffic upon these branch roads will consist mainly of crude products of the forest, mine, and farm, in the transportation of which the question of speed is of minor importance. The expense of laying out, constructing, and operating such local roads must be kept as low as possible. As the traffic of these roads increases, their capacity for handling the same must be correspondingly increased by progressive improvements of road-bed, permanent way and general equipment, and additions to rolling-stock and motive-power. For reasons of economy, many roads of this class are constructed of narrower gauge than the standard.

Gradients.—In respect of the cost of constructing and operating a railroad the admissible gradients play an important *rôle*, since not only the possibility of adapting the road-bed more or less closely to the natural surface without the necessity of resorting to artificial structures (bridges, tunnels, etc.) depends upon them, but also the weight and capacity of the locomotives that will be required, and, consequently, the weight and speed of the trains. There is a grade-limit beyond which a locomotive cannot be employed with useful effect, inasmuch as the power that must be expended to move the engine itself—and therefore not available for haulage—is so great on very steep grades that there is no surplus for useful traction. As the power of the locomotive is brought into action by the grip or friction of its driving-wheels upon the rails, the maximum pulling-power will be obtained when the entire weight of the machine is supported on the driving-wheels, thus giving them the greatest amount of adhesion. Even where this condition is most closely approximated the effect of steep gradients on the tractive power of the locomotive is so serious that they must be carefully avoided, so that the profile of the road-bed shall conform as nearly to a level as the surface-nature of the territory through which it is laid will permit.

To exhibit this detrimental influence of gradients on the tractive power of the locomotive the following example may serve: Assuming the case of an engine weighing (with tender) forty tons, and capable, when exerting its maximum power, of drawing forty-two loaded cars weighing four hundred and twenty tons at the rate of twenty miles an hour on a level, the loads it would be able to draw at the same speed on various gradients are exhibited in the following table—namely:

Grade.	Load that can be drawn at 20 miles an hour.
0 (level)	42 cars weighing 420 tons.
1 in 600	34 " " 340 "
1 in 300	27 " " 270 "
1 in 150	20 " " 200 "
1 in 100	15 " " 150 "
1 in 75	12 " " 120 "
1 in 50	9 " " 90 "
1 in 40	6 " " 65 "
1 in 30	5 " " 45 "
1 in 20	3 " " 24 "
1 in 10	None.

To avoid such serious loss of effective power the earliest railroads were built with the road-bed nearly level, to accomplish which often involved enormous expense. This was rendered imperative on account of the very deficient power of the locomotives. As locomotive-builders learned to increase the power of the machine it became possible to operate roads with steeper gradients, and the railway-train to-day easily scales the heights of the Alps of Europe, and of the Alleghanies, the Rocky Mountains, and even the more formidable Andes, of America. Where the precipitous nature of the ground renders the construction of a railroad upon the surface impossible, or, on account of the cost of its operation, inexpedient, resort must be had to other systems of construction or to tunnels.

Curves.—The curves that should be permitted on the projected line require careful consideration, and will enter largely into the question of selecting the route, inasmuch as they not only cause a loss of locomotive power, but also throw injurious strains upon the locomotive and cars and increase greatly the wear upon the rails. The shorter the radius of the curves, the more pronounced will be their injurious effects. On striking a curve there will be a certain grinding action of one of the front wheels and of the diagonally-opposite hind wheel against the rail, which causes rapid wear and tear of wheels, journals, and rails. Furthermore, as the outside rail on a curve is longer than the inside one, the outside wheel must travel farther in rounding it; but, as each pair of wheels is rigidly attached to its axle, the outer wheel must slip or slide on the rail, which induces additional friction and wear of wheel and rail. These difficulties may be overcome partially by an arrangement of the journal-boxes so as to permit of a certain amount of "end-play" to the axle and by making the tread of the wheels slightly conical, or by slightly increasing the gauge of the road in the curve, or by the device of a "loose wheel," by which one wheel may revolve independently of the other.

Elevation of Rail at Curves.—To counterbalance the effect of the centrifugal force generated in swinging around curves—which is to press the flange of the wheel against the outer rail—the outer rail is given an elevation above the inner one, the amount of elevation being determined by the sharpness of the curve. Inasmuch, however, as the forces here called into play will vary in intensity according to the speed, the weight of the train, and other circumstances, the corrective applied must be such as will be most likely to suit the average condition of practice. The curve, therefore, in spite of the artifices that are employed to reduce its bad effects, remains an evil which must be avoided as far as possible in practice. It may be noticed at this point that, generally, the two evils of frequent curves and steep gradients are found associated in the same road.

Number of Tracks.—Where the projected road promises to acquire future importance, or where it passes through a thickly-settled district, the road-bed should be constructed sufficiently wide and substantial to admit of a double track. The road-bed may be widened and additional tracks laid when the traffic justifies the outlay.

Track-width: Standard Gauge.—Respecting the width of the track, the so-called "standard gauge" (4 feet 8½ inches of width between the rails) is now in very common use in both Europe and America upon all the main railroad lines. This particular width of gauge was adopted by the English as a standard, for no assignable reason other than that it was the common gauge of road-vehicles in England, and has been copied by railroad-builders elsewhere. The advantage of uniformity in gauge in permitting of the interchange of traffic between the different lines of railroad is obvious, and accounts for the very general adoption of the standard gauge. There is still, however, considerable divergence from uniformity. Russia adopts 5 feet as the standard; Spain and Portugal, 5½ feet; Ireland, 5¼ feet. In the United States there was until within the past ten years much irregularity in gauge in various sections, but all the main lines, and most of the secondary lines which diverged from them, have since changed their gauges to conform to the standard.

Narrow Gauge.—There is in all parts of the world a considerable number of railroads of narrower gauge than the standard. In the United States there are thousands of miles of such roads, principally, however, short lines and in new or thinly-settled districts. As such roads can be constructed, equipped, and operated cheaply, they may often profitably be maintained in regions where more costly roads of standard gauge and equipment would prove unremunerative. They are found specially serviceable for the transport of crude materials, such as ores, building-stone, lumber, etc. To avoid the delay and expense of removing freight and passengers from the cars fitting one gauge of road to those fitting another gauge, the car-transfer apparatus devised by Ramsey has been adopted to a large extent in the United States. (See p. 207.)

Other Considerations in Planning a Road.—Besides the points above mentioned in connection with the location of the projected railroad, other subjects are important to consider, such as the future division of the road into sections, the location of stations, the power of the engines, the construction and carrying capacity of the cars for the several forms of service, etc. The engineer of the projected road must have a clear conception of the objects that its projectors have in view, in order that its location, construction, equipment, etc., shall be such that these objects may be attained in the most effective manner and with the least expenditure.

Selection of Route.—The same general principles that govern the choice of a route for a roadway should also govern the selection of a route for a railroad. The standard of perfection is a perfectly straight and level road-bed for the reception of the permanent way. In his endeavor to approximate to this standard the engineer will be confronted with many difficulties that will demand the exercise not only of technical skill, but also of sound business judgment, properly to overcome them. The introduction of many and sharp curves and of steep gradients, while most objectionable because they involve extra cost for maintenance and operation, may be found desirable, because they may save considerable in the first outlay. This will be the case when to avoid them will necessitate excessive outlay for cutting, embanking, and tunnelling. It is the task of the engineer to give due consideration to all the conditions affecting the problem. Engineering advantages will occasionally have to be sacrificed to financial objections, and *vice versa;* so that the route finally adopted must be a compromise to expediency. While the railroad may not be quite straight or quite level, it must not be excessively costly by reason of extravagant outlay for embankments, cuttings, and tunnels to avoid sharp curves and steep gradients; nor must everything be sacrificed to cheapening the first cost of the road by avoiding such features of construction where they should properly be employed, as such saving would often be more than counterbalanced by the increased expense for operation.

Preparatory Work.—The technical preparatory work begins with the selection of the general direction of the proposed road. The region is critically examined with the aid of a good map, the positions of the water-courses and summits are determined, the most advantageous points for bridging the former and crossing the latter are decided. Experimental lines are then run between the points thus located. The adjacent territory on both sides of these lines is carefully gone over, and from the comparison of the data thus collected and collated the route is selected. When this has been determined, the ground is surveyed with accuracy, the road is staked off, longitudinal and cross-sections are prepared, the projected line is drawn to scale, and the exact calculations and estimates of cost are made.

2. EARTHWORK.—THE FOUNDATION.

In the projection of a railroad-line engineers endeavor so to utilize the principle of compensation in the moving of the rock and the earth that the material from the cuttings shall furnish as nearly as possible the amount required to form the embankments.

Earthwork: Embankments and Cuttings.—The earthwork, as it will form the foundation of the road-bed and the permanent way, should be uniformly solid, of ample width, with gentle slopes, and with provision for thorough drainage. The several forms which the earthwork may assume are the embankment (*pl.* 24, *figs.* 1, 2), the cutting (*fig.* 3), and the side-cutting (*pl.* 26, *fig.* 13). It will often happen that the masses removed in excavations cannot be used for the embankments, as when the material is not suitable for such use, when the distance from the cut to the embankment is too great, or when the transfer of the material is impeded by unfinished works (bridges, tunnels, etc.). But when, as is commonly the case, cuttings and embankments follow one another in rapid succession and the excavated material is suited for the purpose, it will be found advantageous to form the embankments, as far as possible, of the materials removed in the cuttings.

According to the nature of the ground, the work in a cutting is carried on with the shovel, pick, and crowbar, or by blasting with gunpowder, dynamite, etc., the high explosives being now generally employed upon hard and compact rock.

Cuttings: Disposing of Material.—The means to be adopted for removing the loosened and broken material will be determined by its quantity, the distance to which it must be transported, and other considerations. Thus, for comparatively short distances, wheelbarrows will be most serviceable; for greater distances, hand-tilting or dumping-cars (*pl.* 24, *figs.* 6, 7), that may be tipped to an angle of 45°. In these cases planks are laid down to serve as a track for wheeling or rolling the load. As the distance increases, dumping-cars drawn by horses are substituted, and a temporary railway laid upon longitudinal strips or sleepers is commonly provided for the cars to run upon (*fig.* 9*a–c*). Finally, when considerable masses of earth or rock are to be removed, the locomotive must be pressed into service (*fig.* 5). According to circumstances, the work of cutting may be started either from the middle or from the sides, and proceed regularly downward to the proper level in a series of benches or terraces. In planning such work it is important to locate the burden-road in such relation to the work being carried on that the loosened material may be loaded on the dumping-cars as directly as possible.

Grades.—The most advantageous grade for burden-roads is 1 : 100, since on such an incline the loaded cars will just about run down by their own weight. In deep cuttings, however, especially at the commencement of the work, it will be impossible to avoid steep grades. In such cases it will often be advantageous to convert the declivity into an inclined-plane railway (of from 16 to 50 per cent. grade), upon which the loaded cars in descending draw up the empty ones by means of a cable passing over a fixed drum or pulley. Where, on the other hand, it is necessary to remove material from the depths of a cutting to high ground at the side, the inclined plane will likewise be employed, with the provision of a stationary steam-engine at the summit to furnish the power for drawing up the loads.

Systems of Cuttings.—Figure 8 (*pl.* 24) illustrates a method of making deep side-cuttings at one time practised in England. In this, the workmen with their barrows are drawn up the slope by horse-power. This method, however, has fallen into disuse on account of the liability of the roadway to become dangerously slippery. Another system of cutting which may occasionally be followed advantageously consists in driving a lateral tunnel or gallery at the bottom of the proposed cutting, and sinking from the top, at several convenient points, vertical shafts to communicate with the gallery. These shafts are gradually enlarged—funnel-shaped—and the loosened material is allowed to drop through them directly into the transport-cars stationed in the gallery below to receive it.

Excavating-machines, or steam-shovels for excavating and loading the material of a cutting, have been devised, and where large amounts of work are to be done they may be used to advantage. Figure 6 (*pl.* 27) very clearly exhibits the construction and method of operation of a machine of this description. The application of such machines is limited, of course, to the excavating and removing of sand, gravel, clay, and the like. Trautwine does not recommend their use where the depth of the cutting is less than 10 feet, for the reason that moving them from place to place involves too great a loss of time. The following statements respecting the serviceability of the steam-excavator are given upon this authority. In stiff soils cuttings may be made about 17 to 20 feet deep without changing the level of the machine. For greater depths, in such soils, the work must be done in two levels, since the bucket or dipper cannot reach so high. But in sand or gravel much deeper cuts may be made from a single level. In appearance and mode of operation the excavator resembles a dredging-machine. A large plate-steel bucket, like a dredging-bucket, with a flat hinged bottom and provided with steel cutting-teeth, is forced into and dragged through the soil by steam-power. It dumps its load by means of the hinged bottom, either into cars for transportation or upon the waste-bank. Each machine is mounted upon a locomotive-car, so that it can be moved from point to point as the work progresses, and carries its own water-tank to supply its boiler.

Embankments.—In the construction of embankments two modes of procedure may be distinguished. In one, the embankment is built up from the base in successive thin layers. This method affords the best results in respect of the solidity of the structure, but, as it can be carried out conveniently only by hand-labor, it is not generally applicable. In the other method, the embankment is extended forward by material dumped or poured upon it from the top. This is the method commonly adopted, as it permits of more rapid construction. If the embankment is advanced full width by this mode of construction, the successive increments form layers extending across the embankment, and a sliding or lateral giving way of the structure need not be feared. Where, however, a narrower embankment is first constructed and this is widened by dumping on the sides, crevices which will endanger its stability may form lengthwise of the structure, and these may become the predisposing cause of its lateral displacement by sliding. In this latter mode of embanking the dumping of the material may often be facilitated by the employment of a crude species of trestle, which is covered up with the earth thrown down, and extended as the work advances. Figure 10 (*pl.* 24) exhibits a simple form of portable bridge supported on scaffolding, which may be shifted along in advance of the embankment as this progresses. Figure 7 shows a burden-car designed to tip forward, which may be used advantageously for this kind of work without the aid of trestles.

The Surface-breadth of the roadway for a double-track road of normal gauge may be taken at about 22 feet. The intermediate distance between two lines of track is 6 feet, which allows sufficient free space for the engines of two trains to pass each other.

Slopes of Cuttings.—Cuttings are made as deep as from 50 to 100 feet below the surface, and embankments as high above the surface. The slopes for cuttings and embankments will be determined by a variety of circumstances, such as the nature of the material in respect of stratification, coherence, and capability of resisting weathering, by the height of the walls or banks, and by the presence or absence of springs. As a general rule, the slopes of cuttings may be steeper than those of embankments, but in sand or earth a rise of one foot for 1 to 1½ or 2 feet is the common practice. In cuttings through solid rock the slopes may be nearly vertical.

Stability of Cuttings.—The stability of the slopes is sometimes increased by planting them with grasses, by sodding, etc. Withes interlaced with stakes form an excellent means of conferring stability, and are occasionally used with good results. The most secure—and generally, also, the most costly—expedient is the walling up of the slopes. Sometimes, as where the line is contiguous to water, protecting-walls of stonework become necessary, as in the case exhibited in Figure 4. In similar situations, where a portion of the slope is under water, piles, cribs of timber, fascines, and the like, may be employed. The materials best adapted for embankments, as well as for cuttings, are sharp sand, gravel, or rubble, as these, while sufficiently insoluble, yet permit free drainage. To insure thorough drainage, lateral ditches are provided, as shown in Figure 3.

Retaining-walls.—Where embankments are built of rock the stones adjoining and forming the face of the slopes should be regularly disposed in courses. Should the rock be readily decomposable, the surface of the slopes should receive a protective covering of soil. Sometimes only the lower portion of the embankment is formed of stone. Again, the configuration of the ground may compel the use of rock embankments with steep slopes. Where these are confined to moderate heights, slopes of 2, 3, or even 4, feet rise to one foot of base may be admissible. Whether the face of the wall with the steeper inclines above named should be laid up in mortar, or whether it will be sufficiently substantial without it, will depend upon whether the rock employed can be laid solidly in layers or not. Where, however, the question relates to the construction of a steep embankment of considerable height, to be filled in with loose materials, retaining-walls solidly laid up in mortar are necessary. Figure 6 (*pl.* 26) exhibits the construction of the retaining-walls of the Kulmbach inclined plane. This is over 100 feet high, with concave slopes.

Forms of Walls.—The cross-section of the retaining-wall may vary considerably. It may be rectangular, with a thickness about one-third its height (*fig.* 1), or trapeziform (*fig.* 2), with the outer face inclined or curved (*fig.* 3). The last named affords the greatest stability with the least expenditure of material. To strengthen these structures, abutments are employed where their use seems to be required (*fig.* 5). Figure 4 shows the English practice of arching between such abutments.

Drainage.—Before commencing the construction of an embankment the ground must be cleared of such materials as vegetable mould, grasses, etc., which would retain moisture, and which cannot sustain the weight of the embankment. It is of the first importance, also, that culverts and cross-drains of ample dimensions should be provided for confining and carrying off the water of small streams, springs, etc., that may lie in the way of the proposed embankment. Larger streams will require bridging. Where marshy ground is to be crossed by a high embankment, two lateral ditches are dug, and the ground is compressed by the gradual settlement of the embankment, until at length it has acquired the necessary stability. While this sinking is going on, the level of the embankment is maintained by fresh additions to its surface. In the case of a low embankment the weight of which is not sufficient to compress a deep marshy soil, the precaution is necessary to build it somewhat higher than is actually required, leaving it to sink to its proper level in time; or if the marsh be a shallow one, the soft ground may be partially or wholly removed and replaced by sand, gravel, stone, etc.

Wherever it is practicable, advantage should be taken of the grades to drain the structures as thoroughly as possible by means of properly-disposed channels communicating with the lateral ditches (*pl.* 24, *fig.* 3), which are provided to ensure thorough drainage. Where a cutting must be made through ground composed of layers of water-bearing strata (such as sand, gravel, and the like) alternating with layers impervious to water, like beds of plastic clay, danger from landslides is to be feared, and provision should be made to guard against such accidents by the liberal use of drain-pipes and channels. Where, as in the case of the railroad over the Brenner Pass, in the Tyrolese Alps, an entire mountain-side must be drained, a system of vertical shafts loosely charged with fragments of rock is constructed, communicating at the bottom with galleries into which the drainage-water is directed, and from which it is delivered far below the road. Where solid strata rest upon a yielding stratum the stability of the cutting is imperilled, and the softer ground must be relieved from pressure by abutments interposed at suitable intervals, being at the same time properly drained.

3. TUNNEL CONSTRUCTION.

Necessity for Tunnels.—Where a line of communication (highway, railway, or canal) is interrupted by a barrier of rock, and where an open cut is impracticable because of the amount of material to be removed, and also where a *détour* or displacement of the line of communication is undesirable, recourse must be had to the tunnel. The first step to be taken in work of this kind is to make a geognostic examination of the rock-formation to be penetrated, to ascertain its character—whether it be hard, soft, friable, gravelly, or unstable (that is, containing quicksand)—in order from these data to determine the most suitable form for the proposed structure, the manner in which the work may most advantageously be done, and the probable length of time that will be required to complete it. Tunnelling, however, will rarely be found expedient until the depth of the cut exceeds 60 feet; and when intended for railway use, it is important that the course of the structure should approximate as closely as possible to a straight line, to lessen the liability to accidents. Tunnel-work in rock of such a nature that it will not serve to sustain itself must be artificially supported by a lining of masonry.

Tunnelling.—The line or axis of the tunnel having been established by survey upon the surface, the work is commonly carried on by driving a gallery through the hill or mountain as rapidly as possible from the two ends, the work being facilitated, where the situation permits, by the sinking of intermediate shafts at convenient points in the axis of the tunnel and driving headings in both directions toward the terminal galleries. By this means the number of points of attack is multiplied, and the time required for the completion of the structure is lessened correspondingly.

Grade and Ventilation.—With respect to grading the practice is not uniform, the plan being sometimes to grade up from both ends, and at other times to give the tunnel an inclination in one direction. The purpose, of course, is to facilitate ventilation and drainage. Except in the rare cases where foul air is met with, no special provision for ventilation will be found necessary, either during construction or afterward, unless the length of the tunnel is considerable—according to Trautwine, about 1000 feet. But when this length is exceeded, such provision must be made while construction is going on, either by means of shafts or by the use of mechanical appliances for forcing air through pipes to the working headings. The substitution of compressed air in place of steam as the motive-power for actuating the drilling-machines employed in modern engineering practice has to a large extent obviated the necessity of using special means for supplying air, the air-compressors at the entrances serving the double purpose. Except in the case of very long tunnels, it is usually unnecessary to provide artificial means of ventilation after construction, although the shafts sunk to expedite construction are not infrequently utilized for this purpose. Tunnels with a single inclination give less trouble on this score than those which grade up from the ends. To avoid the fouling of the air of long tunnels by the locomotives, they are commonly provided with special appliances for condensing steam and smoke during the time of passage.

Mode of Excavation.—The usual mode of excavation consists in driving a passage-way or heading (considerably smaller than the cross-section contemplated for the finished structure), and in maintaining this some distance in advance. This heading is then enlarged to full size. The mode of procedure varies according to the nature of the material to be penetrated. The current practice is indicated by Trautwine as follows: In rock the most convenient plan is to run the heading just below the top of the tunnel, which allows the workmen to drill holes conveniently in the floor for the blasting which must be resorted to in removing the rock (*pl.* 27, *fig.* 5). In earth, on the other hand, it is preferable to drive the heading along the bottom, as this affords the greatest convenience for enlarging the opening to full tunnel-size by loosening the soil and letting it fall. Again, where the tunnel is being driven through earth or other yielding materials, it is necessary carefully to protect the roof and sides of the heading and of the enlarged tunnel-section as the work progresses and before the masonry lining is put in place. This is accomplished by the use of rows of vertical rough timber props and horizontal caps or overhead-pieces, between which and the earth rough boards are placed, to form temporary supports for the sides and roof of the excavation (*pl.* 26, *figs.* 16–18). The props and caps are placed in position first, and the boards are then driven in between them and the earth walls of the excavation. As the masonry lining is carried forward these temporary supports are carefully removed.

In what is sometimes called the Belgian system, the plan is followed of finishing the upper half of the tunnel first, the arch being supported by timbering erected on the floor of the excavated portion. The lower half of the tunnel is gradually excavated to the proper depth and finished in short sections at a time, the finished roof meanwhile receiving such temporary support as may be required.

Timbering.—In Figures 16 to 18 the different plans of timbering employed are exhibited with sufficient clearness to render further description needless. Figures 20 and 21 are views showing the details of a sectional iron framework designed by Engineer Ržiha of Brunswick as a substitute for timbering in tunnel construction where artificial support is called for. The cast-iron segments interposed between the girder and the walls of the excavation are removed one by one as the masonry lining is advanced (*fig.* 19); and when an entire arch-section at the rear may be removed, it is transferred to the front. This plan of operation presents several advantages, and is favorably spoken of.

Subaqueous Tunnelling.—Where a tunnel is to be made under the bed of a river special precautions must be taken to guard against disaster, since the irruption of water constitutes a serious danger. In excavating the first tunnel under the Thames at London the English engineer Brunel, after several failures, adopted the plan of using at the heading a movable bulkhead or shield, which was held in place by beams parallel with the axis of the tunnel and bearing against the finished masonry (*pl.* 26, *fig.* 15). One portion of the bulkhead was removed at a time, the earth behind it excavated to a certain distance, and the section of bulkhead replaced at the advanced position. The bulkhead was thus advanced section by section. The plan of using the movable bulkhead is commonly designated the English system. More recently rotary cutters and other mechanical devices operating in advance of a shield have been proposed (*pl.* 26, *fig.* 22; *pl.* 27, *figs.* 1, 2).

Worthy of notice in this connection is the system of subaqueous tunnelling devised by the American engineer Hall, which is claimed to be a great advance, in point of simplification, over the methods hitherto employed. At the present time (1888) it is proposed to lay a tunnel between Prince Edward Island and the mainland by this plan. Figure 3 (*pl.* 27) illustrates the method. The inventor employs a movable caisson, which is advanced little by little. This is made of heavy iron plates of the form shown in the illustration. Its interior is large enough to accommodate a complete section of the tube of which the shell of the tunnel is to be built, and as each section is put in place the caisson is advanced one length by means of hydraulic jacks placed inside the caisson and pushing against the rim of the last-finished section. The rear of the caisson is furnished with an orifice of circular (or other) section to conform to the determined shape of the tunnel, and is provided with a stuffing-box having a strong but elastic packing, by which means a water-tight joint is formed around the unfinished end of the tunnel. This mode of procedure in subaqueous tunnel construction does away with the necessity of costly caissons and the use of compressed air and air-locks for entrance and egress for the workmen and for removal of the materials excavated, and likewise with the use of the movable bulkheads at the headings, where the material to be penetrated is earth.

Machinery and Blasting Compounds.—Within the past twenty-five years great advances have been made in methods and machinery employed in tunnelling. The discovery and application to blasting purposes of explosive compounds much more powerful than gunpowder, such as nitroglycerine and the numerous mixtures into which it enters as a constituent (known variously under the names of dynamite, giant-powder, explosive gelatine, etc.), and others of different character (rackarock), were probably the incentives that induced engineers to improve their tools and machinery so as to permit these powerful agents to be used to the best advantage. Consequently, the discovery of high explosives has led to great improvements in the construction and efficiency of the tools and machinery used in rock-drilling. The old-time practice of hand-drilling, slow and laborious, has been supplanted by improved power-drills operated by steam (*fig.* 4), or, preferably, in all extensive tunnel works, by compressed air (*pl.* 26, *fig.* 22), increasing perhaps twenty-fold the rapidity of rock-excavation and relieving the workmen of the severest part of their labor.

Ancient Tunnels.—Extensive tunnel works were constructed by the ancients. The oldest of which there is record is probably that known to have been built by the Babylonians beneath the river Euphrates to connect two palaces. Tunnels were frequently formed by the Romans as a part of their superb structures for supplying cities with water, and the aqueducts of the Peruvians and Mexicans included remarkable works of this description. A number of these are still in a state of fair preservation.

Modern Tunnels.—In modern times great numbers of tunnels have been built, principally to facilitate communication by railways. The first Thames tunnel, for years the most notable structure of its kind, was begun in 1825 by Sir M. I. Brunel, a French engineer, who, after several failures, completed and opened it for foot-passengers in 1843. It is 1300 feet in length, 35 feet in width, and 20 feet in height.

The Mont Cenis Tunnel, commenced in 1857 under the superintendence of Sommeiller, aided by the engineers Grandis and Grattoni, and completed in 1871, was the first upon which improved machines for drilling and powerful modern explosives were experimented with and their great advantages over the older methods demonstrated. The engineers in charge of this work, confronted with the difficulty of conveying power for their rock-drilling apparatus to the location of the headings, thousands of yards distant, adopted the use of air compressed to six atmospheres by water-power that was available for the purpose, thus solving at once not only the difficulty of transmitting power to a distance without serious loss, but also to some extent the important problem of ventilation. Figure 22 gives a general idea of the method of advancing the headings, a number of drilling-machines being carried upon a frame mounted on wheels.

Various explosives (gunpowder, nitro-glycerine, giant-powder, and dynamite) were used at different times for blasting. The charges were exploded by means of a magneto-electric apparatus. The blasting was done in front of a movable bulkhead which was advanced with the work. The enlarging and finishing of the tunnel were carried forward as expeditiously as possible in the rear of the headings. In the later stage of this work, the mode of drilling above named was modified by the employment of a large carrier of tubular iron, upon which the atmospheric drills were mounted. As above noted, the ventilation was only partly effected by the drills, and it was found necessary to employ also a ventilating-pipe which delivered several thousand feet of air per minute to the working headings. In this work the height of the mountain prevented the sinking of intermediate shafts along the line. The completed tunnel unites France and Italy through Le Grand Vallon, in the Savoy Alps. Its total length from the northern entrance, at Modane, in France, to the southern entrance, at Bardonneche, in Italy, is 13,393 yards (or about seven and five-eighth miles). The tunnel is 24 feet 7 inches high at the Modane end and 11¾ inches higher at the Bardonneche end, 26 feet 2¾ inches wide at the broadest part, and 25 feet 3½ inches wide at the base. The top is semicircular. The roof and walls are lined throughout with masonry.

St. Gothard and Arlberg Tunnels.—The Mont Cenis tunnel for ten years remained the longest structure of the kind in the world, until the completion, in 1881, of the St. Gothard tunnel, through the Swiss Alps, relegated it to the second place in importance. The length of this tunnel is 16,217 yards (about nine and one-quarter miles). The same general plan of working was followed in this as in the construction of the Mont Cenis tunnel. The Arlberg tunnel, through the Tyrolese Alps, approximately six and three-eighth miles long, making a third Alpine passage, was completed and opened for traffic in 1884. These constitute the most important structures of their class in the world.

Hoosac Tunnel.—In America, the most important tunnel thus far constructed is the one through the Hoosac mountain, on the railway between Troy, New York, and Greenfield, Massachusetts. It is approximately four and three-quarter miles in length. It was commenced in 1856, and after several periods of cessation was completed some twenty years later. Railway tunnels approximating a mile in length are quite numerous.

The Sutro Tunnel, constructed to cut the celebrated Comstock lode 2000 feet below its highest point, to facilitate the ventilation and drainage of the mines, and to afford a passage-way for the cheap and rapid transportation of the ores to a point on the Carson River, is approximately four miles long; and when all the branches contemplated are built, this length will be nearly doubled.

Other Important Tunnels.—Mention should be made of the Stand Edge Tunnel (about three miles long), the Kilsby (one and two-fifth miles), in England; the De la Nerthe (two and one-tenth miles); the Blasy (two miles), on the Paris, Lyons, and Marseilles Railway, in France; and the Hauenstein tunnel (one and two-fifth miles), in Switzerland. In Germany and Austria, except the several Alpine tunnels above described, there are comparatively few long tunnels.

The following tabulation relating to the four principal tunnels of the world may be interesting for reference:

NAME OF TUNNEL.	Location.	Length in miles.	Years under construction.	Cost.	Cost per running foot.	Maximum advance heading in one year in feet.	Date when completed.
Mont Cenis . .	Savoy Alps . .	7⅝	14½	$15,000,000	$356.00	5,365	1871
Hoosac . . .	Massachusetts .	4¾	20	14,000,000	558.00	4,456	1876
St. Gothard . .	Swiss Alps . .	9¼	9¼	11,175,000	229.00	8,235	1881
Arlberg . . .	Tyrolese Alps .	6⅜	5	7,300,000	154.00	11,775	1884

These figures exhibit at a glance the decided progress that has been made in the art of tunnelling, in the cheapening of the cost of such engineering works, and in the greater rapidity with which it is now possible to construct them with the aid of improved machinery, as compared with the engineering possibilities of a few years ago.

Projected Tunnels.—A double railway tunnel under the Hudson River at New York has been partially constructed, though at the time of this writing work thereon has been temporarily suspended. The fact is noteworthy that the plan was attempted of carrying the work forward beneath the river in yielding material (silt, or river-mud) without the use of bulkheads, compressed air at the working headings being solely relied upon to keep the earth in place. A disaster involving the loss of a number of lives compelled the abandonment of this questionable mode of operation.

English Channel Tunnel.—A project of much greater magnitude than any heretofore referred to has been mooted for several years, and the results obtained from a considerable amount of preliminary work appear to have demonstrated its entire feasibility. This is nothing less than the driving of a tunnel beneath the bed of the English Channel to connect England and France. The termini would be in the neighborhood of Dover, on the English coast, and of Calais, on the French side. The advantage of the proposed tunnel for the transport of merchandise without breaking bulk is fully recognized, but political considerations have prevailed thus far to prevent its completion.

Underground Railway Tunnels.—Tunnels are used to some extent for underground railroads in cities. In London a very extensive system of this kind is in operation, which in respect of the magnitude of its traffic far surpasses that of any system of rapid transit in use in any other city of the world. London *Engineering* thus referred to it some years ago: "In London the underground-railroad system has been in operation eleven years, and so great has been its success, so fully does it meet the requirements of the population, that every year adds to its extension. Opened in 1863 with a section of four and one-half miles from Bishop's Road to Farringdon Street, it has been considerably extended, until now (1875) it has a length of thirteen miles, while new extensions are in process of construction. Many millions of passengers are annually conveyed over these underground tracks, which extend beneath the streets in all directions, uniting the principal centres of trade, intersecting all the great railway-lines, and by the marvellous facility for traffic facilitating the enormous transactions of daily business for which London is so renowned." At the present time (1888) there are fifty miles of underground railway in operation in London, carrying the extraordinary number of fifteen million five hundred thousand passengers per mile per annum. On Plate 26 (*fig.* 23) are shown the cross-section of the tunnel and one of the stations of the underground railway of London.

4. ROAD-BED.

The road-bed, intervening between the foundation and the superstructure (cross-ties, rails, etc.), effects the distribution of the traffic burden over a larger surface of the road-foundation, lessening its liability to give way under the weight. At the same time it serves effectually and rapidly to drain the road-surface.

Material of Road-bed.—The material that generally is considered the best for ballasting the road-bed is broken stone, as the angular fragments interlock well and thus distribute the pressure. It permits, likewise, of the free passage of water. Coarse river-gravel affords an excellent material for this purpose. Pit-gravel, on the other hand, frequently contains too much clay to suit the requirements of the case. It is often difficult to procure a suitable ballast; and when such is not obtainable along the line of the road, the engineer in charge of the construction must employ the best material at hand until something better can be obtained. Huntington, in his *Road-Master's Assistant*, recommends mill (furnace) cinder broken fine, when it is procurable, affirming that for the following reasons it has no superior: Besides being elastic, it is dry, clean, free from dust, contains no nourishment for vegetation, and permits water to pass off readily. Its freedom from weeds is a very great economy, a large proportion of the hack-work in summer being avoided on this account, while in winter the road-bed is warmer and clears itself of snow. According to the same author, engine cinders from the yards have like good qualities, but are reputed to be less durable than mill cinders, blast-furnace slag, gravel, or stone. When broken stone is used, it is recommended that the fragments should not exceed in size a cube that will pass through a 2½-inch ring. Gravel, being liable to work out, is not so suitable as stone- or cinder-ballast.

Depth of Ballast.—Respecting the depth of ballast no absolute rule can be laid down, but it is safe to say that it should not be less than one foot, in order to insure the track against displacement from the effects of frost. The ballast is carefully packed under the cross-ties, after these have been placed in proper position, by the use of the tamping-pick (*pl.* 24, *fig.* 19). On many railroads in Germany it is the rule to fill in the road-bed with fine ballast up to the level of the head of the rails. The practice is based on the belief that the cross-ties will be more securely maintained in position and the wood more effectually protected against frost. The advantage of this expedient is questionable, and it is not in vogue elsewhere. The provision of proper drainage is of vital importance for the maintenance of a good track.

5. SUPPORTS FOR THE RAILS.

The rails are supported upon transverse sleepers, or cross-ties, of timber. On some roads the sleepers are of iron or steel, more rarely of stone. Track systems have been tried recently, in which such methods of support are entirely dispensed with.

Cross-ties are usually 9 feet long, 10 inches wide, and 6 inches thick, though their dimensions may vary slightly. They may have a variety of forms, as seen in the illustration (*pl.* 24, *fig.* 17). In the United States the invariable rule is to use hewn timber, sawed timber being employed only when it is impossible to get a sufficient supply of the hewn material. In the early history of railroads granite sills were utilized for supporting the rails, but were found to be very objectionable, on account of their want of elasticity, and were soon abandoned in favor of wooden sleepers.

The Spacing of the Cross-ties is subject to some variation. On German roads the rule appears to be to space them 3 feet from centre to centre. Where the practice is followed of supporting the rail-joints (*pl.* 24, *fig.* 17), the supporting cross-tie is wider than the others. Where, as is usually the case, the joints fall between the ties (suspended joints), the adjacent ties are spaced closer—say about 2 feet. The average English practice is to provide each rail-length (30 feet) with eleven cross-ties, which would correspond to a uniform spacing of 2¾ feet between centres. It is customary, however, to space them more widely in the middle portion of the rails (as much as 3 feet apart), and more closely toward the rail-ends, to afford greater support at the joints. On American roads the spacing of ties is closer, the average being sixteen ties to a 30-foot rail, making the mean distance between the ties about 2 feet from centre to centre. At suspended joints the common rule is to allow 10 inches in the clear between the two joint-ties.

Timber Used for Cross-ties.—In England and North Germany the wood most commonly used for ties is pine or fir, the former lasting from seven to eight years, and the latter from four to five. In South Germany and France oak is commonly used, having a life of from fourteen to sixteen years. In the United States a variety of timber is used for this purpose—namely, chestnut, the life of which is from five to twelve years; cedar, from six to fifteen; hemlock, from three to eight; while oak lasts from five to twelve years, and spruce pine from four to seven years.

Antiseptic Treatment of Cross-ties.—As the rapid decay of the ties involves their frequent renewal, and correspondingly heavy expense, the impregnation of the ties with antiseptic materials, to preserve them against rotting, is very generally practised in European countries. In the United States, where timber is still relatively cheap, the impregnation of ties has not yet come into general use, although the time is near at hand when the increase in cost of timber will force the adoption of this expedient. As the use of suitable impregnating substances will double the life of ties of fir and pine and triple that of ties of beech wood, nearly all the principal European railroad companies, in view of these facts, have erected a suitable plant for treating their ties by one or another of the numerous processes that have been proposed for the purpose. The following methods are those which are in most general use, and which have exhibited the best results in actual practice.

Preservative Processes: Kyanizing.—In the method devised by Kyan corrosive sublimate is the preservative agent. The thoroughly-seasoned timber, hewn to shape, is immersed for about ten days in a dilute solution of this salt. The liquid is then pumped out, and the sediment that has deposited itself upon the ties is washed off. The impregnated ties are then allowed to remain for two or three weeks, to dry thoroughly before being laid down.

The Process of Boucherie, chiefly used in France, employs a solution of the sulphate of copper, which is forced by hydrostatic pressure into the newly-felled tree, causing the sap to be displaced. The impregnating material is contained in wooden tanks placed upon towers from 25 to 40 feet high, whence it is conducted through pipes to the felled trunks. By suitably capping the end of the trunk to be impregnated and connecting the pipe conveying the solution to the cap, the pressure of the liquid column is sufficient to carry the preservative fluid through the log, the sap being forced out at the other end. When the blue copper solution makes its appearance at the opposite end of the log, the operation is finished, the period varying, according to the character of the wood, from forty-eight to one hundred hours. The process of Boucherie is open to the objection that the impregnating material (sulphate of copper) is decomposed by contact with iron, so that the spikes driven into the ties to hold the rails are rapidly corroded.

Burnettizing.—In Burnett's process, which is favorably regarded in Germany, the preservative employed is the chloride of zinc (called Burnett's fluid). The process as practised in Germany is described as follows: The cut cross-ties, to the number of thirty or forty, are piled on a light truck constructed for the purpose and run on rails into a large iron chamber adapted to receive the same and to withstand the subsequent treatment. The chamber is then sealed hermetically, and steam is admitted to it for about three hours, until the wood has attained the temperature of boiling water. The steam-supply is now shut off, and the steam, together with the air displaced from the wood-cells by the injected steam, is permitted to escape from the chamber by opening a valve controlling the proper passage. The interior of the chamber is still further exhausted by means of an air-pump until the pressure within has been reduced to one-third of an atmosphere. By opening another valve, communication is established between the chamber and a vessel containing a solution of chloride of zinc. The latter is driven into the chamber by atmospheric pressure until it fills the chamber completely and forces itself into the pores of the wood. To make the penetration more complete, a force-pump is applied until the pressure within the chamber reaches eight atmospheres. The impregnation is permitted to go on from one to six hours, at the end of which time the cross-ties may be withdrawn from the chamber.

Creosoting.—In the process of Bethell the impregnating materials employed are the oily products obtained from the distillation of coal-tar. As in the process just described, the penetration of the preservative agent is assisted by the employment of pressure. The process is commonly spoken of as "creosoting," from the fact that creosote is one of the principal constituents of the products used. The process has been modified and improved by Seely, Hayford, and others in the United States, but in its general features the operation does not differ materially from that of "Burnettizing," above described. The creosoting process is more expensive than the others, but the results obtained are now generally admitted to be better. In view of the expense, however, it may be preferable often to employ a cheaper process. In addition to the above named, various other fluid preservatives have been tried in this country, such as sulphate of copper, or of zinc, and chloride of barium (Thilmany), chloride of zinc with glue, and tannin (Wellhouse), chloride of zinc and gypsum, etc.

The German railroads, on which the question of preserving cross-ties has been studied with the closest attention, have reached the conclusion that for impregnation creosote and chloride of zinc are about of equal value; but, as the impregnation with creosote costs about three times as much as with chloride of zinc, a majority of the companies employ the latter. Of the sixty million ties laid on the German and Austro-Hungarian railroads, it is estimated that nearly one-half are impregnated.

General Use of Preservative Processes.—In most European countries timber is scarce and correspondingly costly, and, in consequence, its treatment by one or another of the preservative methods above mentioned has been found very advantageous on the score of economy, and is almost universally adopted not only for railroad-ties, but also for engineering structures generally.

In the United States the question of rendering timber more durable by preservative treatment formerly received little attention. The improvident destruction of the forest areas, however, is already beginning to make itself felt, especially in the older-settled sections, and of late the subject has received serious consideration. The conclusion reached by a committee of the American Society of Civil Engineers which reported on the question in 1885 was that "the time has probably arrived when in many sections an economy of from twenty to fifty per cent. a year can be obtained in the maintenance of timber structures and cross-ties by artificially preparing them to resist decay, while in other districts timber is still too cheap to warrant spending money to preserve it." While approving of creosoting as the best process to use, the committee's judgment was that its cost would preclude its use except in a few localities, and on this account, chiefly, the committee recommended Burnettizing as the most advisable process for railroad cross-ties.

When it is considered that there are in round numbers two hundred and fifty thousand miles of railroad in operation in Europe and America, having on the average two thousand cross-ties to the mile, of which it may safely be estimated that one-seventh must be renewed each year, it will be observed that the annual requirement of the railroads for cross-ties reaches the enormous total of 75,000,000 feet, not only involving a vast consumption of timber, but also necessitating a large annual expenditure of money. In the United States, the annual outlay for renewal of cross-ties is more than ten million dollars, and in Europe, where timber is much more expensive, this annual outlay of the railroads must be relatively much higher. In view of these facts, it is not surprising that attempts should be made to substitute materials other than wood for cross-ties.

Stringers.—Wooden stringers (running lengthwise under the rails; *pl.*

20, *figs.* 10, 12, 14, 15; *pl.* 24, *fig.* 9), which were quite common in the early period of railroading, are now rarely used save on street-railways in cities, for which form of service their disadvantages of warping, and of being difficult to bed substantially and to drain readily, are not so objectionable. To maintain the proper gauge of the track, however, it is customary to fasten the stringers to cross-ties laid between them.

Stone Supports for Roadway.—Stone blocks, on which the rail was carried by means of a chair (*pl.* 24, *fig.* 14) of varying pattern, according to the form of the rail, were used in the early days of the railroad in England and elsewhere, but soon fell into disfavor among engineers because of the difficulty experienced in fastening the rail-chairs; furthermore, they proved to be too solid and unyielding, causing rough riding, and consequently were objected to by the travelling public. Latterly, however, their use has been revived on the Bavarian State road, the Taunus road, and others. These blocks, about 2 feet square on the surfaces, are roughly-hewn cubes of hard rock (granite, sandstone, etc.), laid in a bed of well-consolidated materials, and not in freshly-made embankments. The rail is fastened down either by spikes driven into a wooden plug in the stone or by screw-bolts passing entirely through the block. A strip of asphaltum felt is placed between the base of the rail and the block (*fig.* 22), giving a somewhat yielding bearing and serving by its elasticity to counteract the jarring of the train, which otherwise would be serious. To prevent the spreading of the rails, especially on curves, extra cross-sills are introduced at the rail-joints.

Metallic Sleepers.—In place of stone blocks metallic sleepers have come into vogue extensively in tropical countries (Egypt, Algeria, India), and to some extent, also, in France and Germany. One of the best-known and most practical forms of the metallic permanent way is the system of Greaves (*fig.* 23), introduced in 1846. The rail-support in this plan consists of a pot- or bowl-shaped cast-iron sleeper having cast on its summit the chair to which the rail is secured. To give the system the requisite strength and to hold the track to gauge, every alternate pair of sleepers is firmly united by transverse tie-bars of iron, which pass through and are bolted or otherwise fastened to them. In the tops of the sleepers are holes through which the material for packing may be introduced and tamped with a suitable rammer. Griffin has improved this plan of sleeper by casting it so as to give a larger bearing-surface for the rail, and by casting ribs upon it to give it greater strength (South America).

Wrought-iron Cross-ties.—Cross-ties made of wrought-iron were first introduced in Belgium in 1862, and found their way into France and Portugal, and afterward into Germany. The oldest (Belgian) form has a horizontal I-shaped section (*fig.* 29) with oaken blocks as the support and for the attachment of the rails. In Germany the most successful system of this order is that of Vautherin, first introduced upon the Lyons Railway, in France, in 1864. This cross-tie has a section like the letter A with the upper or triangular portion cut away. It is exhibited in Figure 30*c*.

The section of the Vautherin sleeper gives great stiffness, so that even when it is not well packed breakages rarely occur, and the sleepers are not liable to displacement on curves. Figure 30*b* (*pl.* 24) illustrates the mode of fastening the rail to the Vautherin sleeper. To give the rails the necessary inclination, the tie is made slightly curved (*fig.* 30*a*). The Vautherin tie appears to have made an excellent record in service. It is not adapted to a road-bed with broken-stone or slag ballast, but on a roadway ballasted with gravel it answers its purpose admirably. It is reported that, while its cost is no greater than that of an oaken sleeper, it will outwear three of the latter.

Steel Cross-ties.—Cross-ties made of Bessemer steel have also been proposed and experimentally introduced. The Boston and Maine Railroad, in the United States, introduced ties of this material in 1885 on a section of its road near Boston where they would be subjected to very heavy traffic. They apparently have given entire satisfaction. Some years ago, Sir William Siemens, in England, proposed the use of glass for this purpose; but there is no evidence that the suggestion was ever put in practice.

Metallic Permanent Way.—While experiments looking to the substitution of cross-ties of iron for those of wood were being made elsewhere, the engineers of the German railways were striving to develop the longitudinal permanent way in metal, the object of their efforts being to produce a rail which when laid directly upon the road-bed should have sufficient rigidity to support the traffic-load without displacement. A rail of this description (*fig.* 24) was proposed in England in 1849 by Barlow, but did not prove successful in practice. The system of Hartwich embodies the same principle. In this, the rail has a broad, flat base, which rests in and is bolted to a metallic base-plate, and the adjoining rails are secured to one another by means of a fish-plate union. The gauge of the way is maintained by transverse tie-bars at suitable distances apart. The Hartwich iron way appears to have met with more favor in Germany than elsewhere. Figures 25*a–c* shows a section of the road-bed prepared to receive this rail, and the mode of fastening and joining the rail.

Hilf's Metallic Way.—While in the Hartwich system the rail and its longitudinal sleeper are united in a single piece, the Hilf metallic permanent way, another German system, is formed of two parts—namely, a rolled longitudinal sleeper of peculiar form and a comparatively light flange-rail of steel. The cross-section of the sleeper resembles the letter E with angles bevelled and laid face down, so as to present a flat upper surface, to which the rail is secured by bolts and nuts. The adjoining rails are united by fish-plate connections, and the gauge is preserved by means of transverse tie-rods secured at both ends with nuts. One of these tie-rods is used for each length of rail (30 feet). The Hilf system is very well spoken of as being simple, cheap, easily laid and maintained, and has shown good endurance in service. It has given excellent results on the Nassau (German) railways. A cross-section of the road-bed with Hilf's system, and a rail-section exhibiting the mode of fastening employed, are seen on Plate 24 (*figs. 26a, b*).

Schiffler's Metallic Way.—The head of the rail is the portion that suffers the most from wear: the web and base remain in good serviceable condition, while the head may be so badly worn away as to be unserviceable. Taking advantage of this fact, the German engineer Schiffler of Brunswick devised a metallic permanent way in which the rail-head is made of cast steel and so arranged as to be removable and replaceable. Figure 28 shows a section of the Schiffler permanent way, in which the rail-head of steel is seen attached by bolts and nuts to a longitudinal sleeper formed of two angle-irons. An iron reinforcing plate is introduced below the rails at joints, and the gauge is preserved by the use of transverse tie-rods or strips. A plan similar in general principle to the foregoing was employed in the construction of the Hanover State Railway. It is exhibited in section in Figure 27. The longitudinal sleeper forming the rail support and base consists, in this case, of two obtuse-angled plates of rolled iron, between which the rail-head is secured by bolts and nuts in the usual way. The gauge is preserved by transverse plates of flanged iron, and, to strengthen the sub-rail to resist longitudinal displacement, saddles of T-iron bent to proper shape are riveted to the under side of the sub-rail at intervals, as seen in the sketch.

Composite rails of the kind just described present difficulties in laying with accuracy and maintaining in alignment, especially on curves. Indeed, taking the experience gained with the entire system of metallic permanent way, of which many forms have been proposed and experimentally tested in addition to those herein described, it would be unsafe to say more than that it has been demonstrated that iron may be substituted in place of timber for roadway sleepers.

6. Rails and their Fastenings.

Early Forms of Rails.—The first rails were made of cast iron, and continued in use until Birkenshaw of Bedlington, Durham (England), made the first rolled rail of wrought iron, the metal, while hot, being passed between grooved rollers of the required pattern. The cast-iron rails had several disadvantages. They could not be made in lengths exceeding 1 or 2 yards, and they possessed so little elasticity that they were readily broken, not only by concussion, but also where the support of the sleepers was insufficient. The first rolled rails—the "fish-bellied" pattern, laid in cast-iron chairs—were modelled after those of cast iron. Robert Stephenson is believed to have been the earliest to introduce (about 1838) rolled rails of uniform cross-section. These were at first supported upon longitudinal sleepers, but the plan was soon abandoned in favor of the cross-tie system, now almost universally employed.

Wrought-iron and Steel Rails.—The rolled rail of wrought iron was decidedly superior to the cast-iron rail, and, its length and weight being increased to conform to the progressive increase in the weight of locomotives and trains, it served its purpose passably well for thirty years. Within the past twenty years, however, there has been an enormous growth of railroad traffic. To accommodate this, the power and weight of locomotives have been materially augmented to enable them to draw heavier trains, the average speed has been raised, and powerful mechanical appliances have been introduced to permit of the quick stopping of the trains. Consequently, the wear of the rails has been greatly increased, and, had not the development of the Bessemer steel process, proceeding coincidently with the growth of railway traffic, made it possible to produce rails of much greater power to resist wear than the rolled-iron rail, the railway system, as Mr. D. K. Clark forcibly puts it, "would have broken down under the enormous growth of traffic." At the present time iron rails have practically gone out of use, and upon all the principal railway lines of Europe and America, Bessemer (and to a slight extent, also, open-hearth) steel rails have taken their place. How completely this statement may be verified by American practice will appear from the fact that during the year 1887, out of the total production of 2,139,640 tons of rails, 2,119,049 tons were of steel, and only 20,591 tons of iron.

The life of a steel rail is commonly estimated to be six times that of an iron rail of the same weight. This is an understatement, as there are many situations (in and about stations, in yards, etc.) where, under the weight of the ponderous freight-engines employed in shifting and making up trains, a steel rail will outwear fifteen or twenty rails of iron, which latter would be so badly battered and laminated as to require replacement after one or two years of service, the steel rail in the same period exhibiting little, if any, signs of wear.

Rail-fastenings.—In respect to the form of the rail and the mode of fastening, the following general types may be recognized—namely, the chair-rail, almost universally used on the British railways (*pl.* 24, *fig.* 18), in which the rail is supported in cast-iron chairs on cross-ties of wood or other material; the longitudinal-sleeper (or stringer) system (*fig.* 9), in which the rail is continuously supported: restricted, at present, to tramways or street railways in cities; the flange-rail system (*fig.* 17), with a broad-base rail secured directly to cross-ties: in general use in Germany, France, and elsewhere in Europe, and universally in the United States and Canada; and the metallic permanent way, in which the superstructure is entirely of iron (*figs.* 23–30): in use to a limited extent in various European countries.

The Forms of Rails that have been devised are legion, but it will suffice to refer to those only that have come into general use. These are (1) the flat, or street-car, rail (*fig.* 9*c*); (2) the bridge, or Brunel, rail (*fig.* 11); (3) the single-headed chair-rail (*fig.* 14); (4) the double-headed chair-rail (*fig.* 13); (5) the broad-base rail (*fig.* 12), called variously the flange-rail, T-rail, Stevens, or Vignoles rail; (6) the Barlow rail (*fig.* 24). At the present time the flange-rail and the chair-rail (single and double headed) are the two forms that are nearly universally employed, and these alone need to be considered in connection with the question of the most advantageous form of rail. The strain to which a rail will be subjected is that resulting not only from the vertical pressure of the load, but also from a lateral pressure, usually from the swaying of the moving load from side to side. The rail, therefore, in addition to a sufficient cross-section to withstand the first strain, must have sufficient lateral stiffness to withstand the second.

The Flange-rail, with its broad base and direct attachment to the cross-ties, would seem to have the advantage, in this respect, of the chair-rail, with its narrow base and indirect form of fastening. The ease with which the flange-rail may be secured to the sleeper with fastenings of the simplest kind is another notable advantage in its favor; there is also a decided gain in economy in the case of the flange-rail in dispensing with the chairs. These advantages have been deemed sufficient to induce the almost universal adoption of the flange-rail in Continental Europe and America.

The Double-headed Rail, keyed in chairs, was at one time in general use in France, but it has been removed and the flange-rail substituted, with its simpler mode of fastening. In Great Britain the chair-rail, in the form of either the doubled-headed rail (*pl.* 24, *figs.* 13, 15) or the bull-headed rail, is in common use; to a limited extent, however, the flange-rail is in use in Ireland. The advantages claimed for the double-headed rail are that it may be turned or reversed when the head is worn; that, the mode of fastening being less rigid than that of the flange-rail, it causes less disturbance of the superstructures; and that it involves less labor for maintenance. Of these alleged advantages, the first named appears to be the only one of any importance. On the other hand, the under side of the reversible rail is liable to be indented by hammering against its seat, unless the precaution is taken to cushion the blow of the wheels transmitted by passing loads, and the mode of securing the rail in the chair by means of wooden keys does not altogether prevent the "creeping" or longitudinal displacement of the rail.

The "Bull-headed" Rail, according to Mr. D. K. Clark, is the form in use in the majority of the railway lines of England and Scotland, and possesses all "the advantages of the double-headed rail, except that, like the flange-rail, it is not reversible." Lacking the element of reversibility, the advantages of the bull-headed rail are questionable, and its very general use in the United Kingdom, notwithstanding, is not readily explained.

Size and Weight of Rails.—The dimensions of rails vary considerably according to the traffic weight they are to bear. In English practice, according to Clark, doubled-headed and bull-headed rails "are rolled to a weight of from eighty-two to eighty-six pounds per yard; the heads are made from $2\frac{1}{2}$ to $2\frac{3}{4}$ inches wide; the webs are from $\frac{5}{8}$ to $1\frac{3}{16}$ of an inch in thickness, and the height of the rail varies from $5\frac{1}{4}$ to $5\frac{5}{8}$ inches." The usual length is 30 feet. The weight of rails on standard-gauge railroads in the United States will vary from sixty to eighty pounds per yard. The common practice is to employ rails of from sixty to sixty-five pounds per yard. Thirty feet long and $4\frac{1}{2}$ inches high are usual dimensions. Rails weighing as much as one hundred pounds to the yard are in use on certain English roads where the traffic is unusually heavy, and also to a limited extent in the United States (Pennsylvania Railroad).

Rail-bending Machines.—For adapting rails to curves, rail-bending machines of various forms are employed. Plate 24 (*figs.* 20*a*, *b*) exhibits a machine for this purpose. In this the ends of the rail are drawn down by means of levers. Figure 21 exhibits a rail-bending machine with adjustable rollers. Hydraulic machines for the same purpose are in common use.

The Rail-chairs are of cast iron, weighing from thirty to fifty pounds and having a width of from $4\frac{1}{2}$ to 8 inches. The rails are secured in place in the chairs by means of keys of hard wood (oak) or iron, and frequently are supported on cushions of hard wood placed on the chairs, which afford an elastic bearing for the rail. This arrangement not only contributes to the smooth running of trains, but also prevents the indentation of the lower head of the rails. Such modes of support are seen in Figures 14 and 15. As above remarked, the use of the chair-rail is confined principally to Great Britain, the general verdict of railway engineers being that it is a cumbrous and expensive expedient without any notable offsetting advantages.

Rail Connections: Fish-plates.—In order to prevent the vertical or horizontal displacement of the rails at the joints from the weight of passing trains, the ends of contiguous rails are firmly united by so-called "fish-plates" and angle-plates of iron or steel of various forms. This mode of union is seen in Figures 17 and 18. A typical form of fish-plate is shown in Figure 12. Figure 25*c* exhibits the very powerful fish-plate joint of the Hartwich rail. These devices consist of two parallel iron or steel plates placed within the side-channels of the rail and firmly fastened to the latter and to each other by bolts and nuts (of which there are two to each rail-end) passing through the web of the rail. These plates are commonly rolled in long bars, which are afterward cut off in proper lengths, usually 2 feet, and the weight of the complete joint, including bolts and nuts, is about twenty pounds. The sharp undercut rail-head (*fig.* 12) is more favorable for this form of fastening than the sloping form (*fig.* 16), since the former offers a better bearing-surface and makes a stronger joint. To give greater vertical stiffness to the joint, the fish-plates are in some cases carried down along the lower member of the rail, and occasionally are turned under it (clip fish-plates).

Angle-plates for rail-joints are likewise used to make a stronger union (*pl.* 25, *fig.* 3). These have flanges which extend down over the foot of the rails and bear upon the cross-ties (*fig.* 9), to which they are spiked. Figures 10 to 12 show various rail- and joint-sections used upon American railroads.

Plate-fastenings.—To allow for their expansion and contraction by changes of temperature, the rails are invariably laid with a slight space between them. The common rule in this respect on American railways is to allow $\frac{5}{16}$ of an inch space in winter and $\frac{1}{16}$ of an inch in summer. The holes in the fish- and angle-plates are for this reason made oval, to allow for the end movement of the rails. The shoulders of the bolts, immediately under the heads, are likewise given a corresponding oval section, to conform to the shape of the hole in the fish- or angle-plates into which they fit. By this expedient the bolt is prevented from turning when the nut is screwed on.

Nut-locks.—Much difficulty is experienced in keeping in place the nuts, which the almost continuous vibration the rail is subjected to by the passage of trains tends to loosen. To guard against this, many forms of nut-locks have been designed. A favorite artifice to meet the difficulty is that of rolling the fish- or angle-plates with a longitudinal groove about ⅛ of an inch deep along their entire length. This groove is just wide enough to receive the head of the nut, and is intended to prevent the nut from unscrewing.

Bridge-joint.—Many other forms of joint have been proposed, and to some extent introduced in practice. The Fisher "bridge-joint" (*pl.* 25, *fig.* 5), an American invention, is one that has met with favor. In contradistinction to the fish- and angle-plate joints, which apply the support under the head of the rail, the Fisher joint applies it under the base. From Trautwine's description, it consists of a flanged iron beam about 6 inches wide and 22 inches long, which extends across and is spiked to the two joint-ties. The two rail-ends forming the joint rest upon this beam and meet at the middle of its length, and are held down to it by a single U-shaped bolt with a nut on each leg. The corners of the rail-flanges have rounded notches, through which the bolt passes, and a wedge-shaped piece with a hole, through which the shank of the bolt passes, is placed over this and rests upon the rail-flanges, giving a level bearing for the nut. This form of joint does not require the sharp undercut head that is necessary where the fish-plate fastening is used, so that its adoption permits of the employment of the stronger pear-shaped rail-head. Furthermore, it obviates the necessity of drilling or punching the web of the rail.

Supported and Suspended Joints.—According as to whether the joint rests directly upon a cross-tie (*pl.* 24, *fig.* 17) or is placed between two ties (*fig.* 18), the terms "supported joint" and "suspended joint" are used respectively to distinguish them. The suspended joint is in vogue upon the majority of roads, experience having shown that this disposition affords ample strength and less liability to injury of the rail-ends. For securing the rail to the cross-tie, hook-headed spikes (*fig.* 17) are commonly used. These are driven in alongside the foot of the rail and on both sides in such a manner that the hooked head of the spike overlaps and grasps the base of the rail. The supported joint was formerly very generally used in connection with chairs of wrought iron of various patterns. A simple plate of wrought iron drilled or punched with holes for the admission of the spikes is still used in Germany to some extent.

Importance of Condition of Road-bed and Track.—Upon the condition of the superstructure of the road-bed and its maintenance in the most excellent condition will depend in large measure not only freedom from accidents, but also the railroad company's ability to conduct its traffic with economy and despatch. The price of safety is eternal vigilance, and the continued good condition of the road-bed and track can be assured only by some well-devised system of daily inspection and constant repair. The proper management of this important branch of the service is effected by the division and subdivision of the road into sections and sub-sections, to each of which there is assigned a well-organized body of trained officials and subordinates, who are responsible for the condition of the section placed in their care.

Road Division.—The Pennsylvania Railroad, for example, is divided into Grand Divisions, Superintendents' Divisions (each about one hundred miles in length), Supervisors' Divisions (about thirty miles), and Subdivisions (two and one-half miles). This company has in practice a system of premiums to supervisors and foremen for the excellence of condition of the roadway under their charge—a plan that has been found to work admirably in practice, and has doubtless contributed in no small degree to the maintenance of its road-bed and track in that high condition of excellence for which it is famous both in the United States and in Europe.

Rules for Road Inspection.—It will be useful at this point to indicate some of the rules issued by the company for the direction of the division officials, since they are instructive in exhibiting the care which is bestowed upon minor details:

"The track must be in good surface; on straight lines the rails must be on the same level, and on curves the proper elevation must be given to the outer rail and carried uniformly around the curve. The elevation should be commenced from 100 to 150 feet back of the point of curvature, depending on the sharpness of the curve, and increased uniformly to the latter point, where the full elevation is attained. The same method should be adopted in leaving the curve. The track must be in good line. The splices must be properly put on, with the full number of bolts, nuts, stop-washers, and stop-chairs. The nuts must be screwed up tight. The joints of the rails must be placed midway between the joint-ties, and the joint on one line of rail must be opposite the centre of the rail on the other line of the same track. In winter a distance of $\frac{5}{16}$ of an inch, and in summer $\frac{1}{16}$ of an inch, must be left between the ends of the rails, to allow for expansion. The rails must be spiked on the inside and outside of each tie on straight lines as well as on curves.

"Cross-ties must be properly and evenly spread, sixteen ties to a 30-foot rail, with 10 inches between the edges of the bearing-surfaces at joints, with intermediate ties evenly spread a distance of not over 2 feet from centre to centre, and the ends, on the outside on double track and on the right-hand side going north or west on single track, must be lined up parallel with the rails. The ties must not under any circumstances be notched, but, should they be twisted, must be made true with the adze, and the rails must have an even bearing over the surface of the ties.

"Switches and frogs must be kept well lined up and in good order. Switches must work easily, and safety-blocks must be attached to every switch-head. The switch-signals must be kept bright and in good order.

"Ballast must be broken evenly and not larger than a cube that will pass through a 2½-inch ring. There must be a uniform depth of at least 12 inches of clean broken stone under the ties. The ballast must be filled up evenly between, but not above, the tops of the ties, and also between the main tracks and sidings. In filling up between the tracks large stones must be placed in the bottom, to provide for drainage; but care should be taken to keep the coarse stone away from the ends of the ties. At the outer end of the ties the ballast must be sloped off evenly to the sub-grade. The road-crossing planks must be securely spiked; the planking should be ¾ of an inch below the top of the rail and 2½ inches from the gauge-line. The ends and inside edges of planks should be bevelled off.

"Ditches must be graded parallel with the track, so that the water may pass freely during heavy rains, and that the road-bed may be thoroughly drained. The lines must be well and neatly defined and made parallel with the rails. The necessary cross-drains must be put in at proper intervals. Earth taken from ditches or elsewhere must be dumped over the banks and distributed over the slope. The channels or streams for a considerable distance above the road must be examined, and brush, drift, and other obstructions removed. Ditches, culverts, and box-drains must be cleared of all obstructions and the outlets and inlets of the same kept open, to allow a free flow of water at all times.

"Telegraph-poles must be kept in proper position, and trees near the telegraph-line must be kept trimmed, to prevent the branches touching the wires during high winds.

"All old material must be gathered up at least once a week, and neatly piled at proper points. Briers and underbrush on the right of way must be kept close to the ground. Station-platforms and the ground about them must be kept clean and in good order."

Plate 25 (*fig.* 14) shows a sample track of this road furnished with a track-tank for taking on water for the supply of the locomotive while the train is moving at high speed. Figure 15 is a view of a signal-station of this road. Figure 8 shows a typical cross-section of its road-bed, and Figures 3 and 9 the manner of making a connecting-joint between rails.

7. Turnouts and Switches.

Turnouts.—On single-track railways, on which trains must be run in both directions, it is necessary to provide some means whereby one train may turn from the main track to permit another to pass by. Again, it is necessary to provide means whereby one train may be able to pass another going in the same direction, and in the case of a double track it will often be required to transfer a train from one set of tracks to the other. To meet these requirements, turnouts are provided at various points along the line of the road, their number being regulated by circumstances and by locality. To connect the turnout with the main track, or, in the case of the double track, to connect the two tracks with each other, various devices have been invented, of which, however, the one most commonly used is the switch. From both tracks branch-tracks are laid, curving in opposite directions and connected by a straight piece of track, the entire arrangement being called a turnout. The forward part of the device, from the point where the tracks to be united separate into branches at an acute angle to the crossing of the main rail by the outer one of the turnout, is designated specially as the switch, while the rail-section at the point where the rails diverge is called the frog (*pl.* 24, *figs.* 33, 34).

Cross-switches.—Turnouts lying in opposite directions between two tracks to be connected and symmetrically disposed between the two are termed cross-switches (*pl.* 28, *fig.* 3). Where one track intersects another, we have a crossing. On Plate 24 (*fig.* 31) is shown a crossing at a very acute angle, in which the transfer of trains from either of the main tracks to the other may be accomplished. In this arrangement, besides the simple frogs at the ends of the switch, two double frogs are provided at the central part.

Stub-switch.—A simple form of switch in general use is the so-called "stub-switch," in which the switch-rail (that is, the movable section of rail inserted between the main and the side track) has blunt or square ends, which can be thrown, by means of a switch-lever, in line with one or the other set of tracks. This arrangement is seen on Plate 25 (*fig.* 7). It is evident that in the event of the displacement of a switch of this kind the train will be derailed.

Point-switch.—In the split-, tongue-, or point-switch the switch-rail is pointed. The operation of this type of switch will best be understood from the diagram (*fig.* 6), in which the flanges of the rails are omitted for the sake of clearness. The upper part of the figure exhibits the switch set for the main line; the lower part shows it set for the turnout. The outer two rails of the combination—the so-called "stock-rails"—are continuous, and are spiked to the ties throughout. By means of fish-plates the heels of the two pointed switch-rails are usually fastened to the ends of the rails which lead to the frog. The pointed ends of the switch-rails are left free, to be moved about their heels or fulcrums. The pointed or free ends of the switch-rails are connected with each other by means of connecting-bars, and are thrown so as to make communication with either the main line or the turnout by means of the switch-lever (*fig.* 13). The pointed end or "toe" of each switch-rail permits it to fit close up to the head of the main-track rail, with which it may be in contact. On this account the name "point-switch" is commonly applied to this type of switch. That the weight of the passing train may not come upon the thinnest portion, where the metal is not strong enough to bear it, the top of the switch-rail, from the point some distance back, is made somewhat lower, so that the pointed portion shall lie under the head of the main rail. As a precaution to prevent the possibility of a wheel-flange striking a point, short sections of rail—called "guard-rails"—are laid down opposite the parts, close to and parallel with the main rails.

Safety-switches have been devised to avoid the frequent accidents caused by misplaced switches. These are so contrived that trains will be able to pass them safely even if they are misplaced. Such is the Wharton Safety-switch (*pl.* 25, *fig.* 4), used upon the Pennsylvania and other roads in the United States. In the case of stub-switches, safety-castings are sometimes provided, which are bolted to their sides, and which, in the event of misplacement of the switch, receive the flanges of the wheels of a train and guide them safely to the switch-rails. Safety devices in connection with switches are of no avail when the moving train faces the switch, seeing that in such case it must go the way the switch is set, whether right or wrong. Various forms of switches and their attachments are shown on Plate 24 (*figs.* 31–34).

Switch-stands.—The throwing of the points of the switch is effected by means of a lever pivoted in a cast-iron frame—the "switch-stand." The lower end of the lever is suitably attached to the connecting-bar joining the movable ends of the switch-rails (*fig.* 31). Provision is made for securely locking the lever when it is set either way, and frequently a counterweight is attached to its free end, to assist in bringing it to its proper place. The upright stand commonly used is shown on Plate 25 (*fig.* 13). The stand is provided usually with two notches, to one or the other of which the lever may be secured by some convenient locking device. Where, as in the case of stub-switches, it may be necessary to have three throws, three notches are arranged accordingly. The top of the switch-lever is usually furnished with a target, which enables the engine-driver readily to observe which way the switch is set. The "ground-lever" or "tumbling-lever" stand is largely used in the United States. In this form the lever lies upon the ground in whatever position the switch may be set. It is convenient, as it occupies very little space. A colored target or a lantern may be connected with this, as with the other form, to indicate to the engine-driver the position of the switch.

Turntables.—It would obviously be very inconvenient, were it necessary, to conduct all the movements of trains and locomotives solely with the aid of switches, and this inconvenience would be felt especially at important stations. For the manipulation of entire trains with the locomotive, the switch and the turnout afford the only serviceable method; but for the more rapid transfer of rolling-stock, especially of single locomotives and cars, from one track to another, or into round-houses, shops, etc., other appliances are used, by which a sudden change or complete reversal of direction may be made. These movements are effected by turntables (*pl.* 28, *fig.* 13; *pl.* 31, *fig.* 1), or, where a lateral movement only is called for, by a travelling platform such as that shown on Plate 28 (*fig.* 14).

The turntables now in universal use in railroad shops and yards, and at all important stations, consist of a platform to which, by suitable mechanical artifices, motion can be imparted in a horizontal plane. The top of the platform carries one or several tracks of rails. The platform is rotated about a central pivot and at the outer end carries rollers, on which it turns, the rollers running upon a circular track. The turntable is made long enough (from 40 to 60 feet) to accommodate a locomotive with its tender. The frame is either of wood (where it is housed) or of cast or wrought iron. The table is usually placed in a masonry-lined pit so adjusted in respect to height that the tracks it carries on the platform shall be on a level with that of the rails of the tracks with which it is intended to make connection. The platform is made occasionally in the form of a cross, providing for two tracks at right angles to each other, or, for greater convenience, it may cover the whole of the pit and carry a number of radiating tracks. To reduce the friction as much as possible, the centre-bearing is provided with anti-friction rollers or equivalent devices. Adams's (English) turntable, referred to by Knight, floats in a water-tank. The turntable is moved either by a lever or by wheel-work, or occasionally, where it is in constant use, by a small steam-engine carried on the platform. A cross-section of the form of turntable largely used in the United States is shown on Plate 31 (*fig.* 1).

The Transfer-table (*pl.* 28, *fig.* 14) consists of a section of track supported on a suitable carriage. The carriage is moved forward and backward on a depressed track at right angles to the track-rails with which connection is to be made, so that the track on the platform carrying the locomotive or car may be aligned with any set of them to which it is desired to transfer it. The Figure exhibits the construction of one of these transfer-tables, and the mechanism by which it is actuated.

Car-transfer Apparatus.—The value of narrow-gauge railroads as feeders depends much upon the facilities for handling through freight with economy and despatch. By means of the Ramsey car-transfer apparatus, the cars of the standard gauge can be transferred to the narrow gauge without breaking bulk. By this device, the trucks under the cars are removed expeditiously and easily, and others are substituted which are adapted to the gauge to which it may be necessary to change.

The means employed to effect this change of trucks consists of a depressed portion of the main tracks of the roads of both gauges laid parallel one within the other (*pl.* 31, *figs.* 12–14), with other tracks of the grade of the main line at the sides of this depressed portion, extending somewhat beyond both ends of the incline entering the depressed portion of the track (*fig.* 13). Upon these side-tracks are fitted wheeled trucks, which, being placed at the sides of a car before entering the incline, and having beams or bars placed across them under the body of the car (*fig.* 12), carry the car-body at the grade of the road, supported upon the side-truck and tracks, while the truck of the car descending the incline is disengaged and remains in the depressed portion (*fig.* 13). As the car progresses, the king-bolts engage with trucks previously placed on the depressed track and having wheels of the other gauge, and these trucks, rising on the other incline, receive the weight of the car-body and permit the withdrawal of the beams. The temporary supporting-trucks are thus disengaged, leaving the car ready to run upon the road of another gauge.

By the simple artifice of effecting this transfer upon side-tracks laid with a sufficient gradient to supply propelling-power adequate to carry the cars by gravity over the depressed portion of the track and to lift the new set of trucks upon the incline to the road of differing gauge, the necessity for the application of motive-power in effecting the transfer is obviated. This system of transferring cars has proved of great value in the railway service of the United States (where until recently divergencies of gauge were very numerous) in saving time, labor, and expense.

8. DRAINAGE, ROAD-CROSSINGS, ROAD-DIVISIONS, ETC.

Drains.—To lead off the watercourses that intersect the road, suitable provisions must be made by means of structures that will vary according to the size and direction of the stream and the nature of the available building material. Where the amount of water to be carried across the road is very small, drain-pipes constructed of cast iron, earthenware, cement, asphaltum, etc., may be made use of for the purpose (*pl.* 26, *figs.* 7, 8). The ends of these drains are commonly built in with masonry floor and side walls and provided with a pit of masonry at the entrance, to serve as a mud-receptacle. Covered drains of masonry are used for watercourses of somewhat larger volume (*figs.* 9, 10).

Culverts.—Where the stream to be spanned is still larger, arched culverts (*figs.* 11, 12) are resorted to, the arches of which are given usually a covering of cement or asphaltum, to protect them against the infiltration of moisture from the overlying material of the embankments. Where the descent is comparatively steep (*figs.* 13, 14), the floor of the drain or culverts is sometimes stepped; but this arrangement, which conducts the water by a series of cascades, is apt to be severe on the masonry. The smooth pavement in the form of a flat inverted arch is given commonly the preference. Special care must be observed to secure unyielding foundations under high embankments, lest the superincumbent weight should cause settlement or distortion of ground by lateral pressure.

Gutters.—Where the vertical distance from the bottom of the creek or rivulet and the road-surface is insufficient to permit of a covered drain or culvert, an open gutter is formed, in which case either the two adjacent cross-ties rest on the stone side walls, or, if the drain be too wide, the track is supported on iron carriers resting on the walls. As, on the one hand, the arched drains, by increasing dimensions, gradually develop into stone bridges, so, on the other hand, the carriers over the open drains may be looked upon as iron bridges in miniature.

Road-crossings.—The railway necessarily intersects many roads, public and private, which for convenience of travel must be left open. In all cases where this is practicable, and especially in cities and towns, such crossings should not be made at grade, but should be carried either above or below that of the railway. In Europe, where many of the railways are operated by the government, a much more exclusive control of the roadway is exercised than in the United States. Trespassing on the tracks is forbidden, under penalty, and road-crossings are everywhere carefully guarded. Should the road and the railway be on the same level, or should there be a slight difference in height, requiring trifling modification by levelling, a crossing is commonly made at grade, which crossing—at least, on principal lines—it is the custom to provide with a gate or other safeguard that may be closed to prevent accidents while trains are passing the point.

To avoid railroad-crossings at grade, the railway must be made either above or below the highway. Where the railway is an elevated crossing, the depressed highway resembles the arched or open drains above mentioned, except that the floor is arranged as a highway with the necessary width. Elevated crossings are viaducts of wood, stone, or iron furnished with one or more openings, according to the width of the roadway. Depressed railway-crossings are usually seen where the railroad passes through cuts or between embankments. Even in cases where the conformation of the ground would make crossings at grade the easier and cheaper course, overhead crossings are considered preferable, because they are safer and require no attendant to guard the place. The rapid growth of a multitude of towns and cities along the lines of railways extending into new territory is responsible for the very general existence of grade-crossings. Crossings at grade are rapidly disappearing from the more important cities, but in a great number of situations, unfortunately, they still prevail, and they will disappear only when the inconvenience and the danger resulting from them become insupportable.

Safety-gates.—These gates are commonly placed in charge of the signal- or flagman, who thus combines the functions of a watchman with those of a signal-man. Where two grade-crossings happen to be near enough together, the services of one flagman may suffice for both gates or bars, which are operated, the one directly and the other by some connected mechanism. The gates or barriers that guard the grade-crossings vary greatly in construction and mode of operation. In some cases a weighted lever is employed, which is raised and lowered; in others the barrier is made to turn upon a pivot or moves on rollers, or is made of a number of jointed levers that may be projected across the roadway. Some are so devised that they may be operated by a signal-man from a considerable distance. For greater safety, the barrier is often furnished with automatic bell-signals, and, in addition to these safeguards, printed signs of warning are erected at the approaches to the crossings. Figure 16 (*pl.* 28) exhibits one of the many devices employed for this purpose.

Road-divisions.—The road is made up of divisions, sections, sub-sections, etc., each of which is under the charge of special officers and employés (p. 203), and these divisions, etc., are designated by numbers, letters, and other arbitrary symbols. It is customary to provide mile-stones or iron tablets to indicate the distance from terminal points of the road or from main stations. It is also usual to denote every change of grade by some convenient method which will show not only the grade, but also the distance for which it remains constant.

Track-surveillance.—The road is kept under constant surveillance by the trackmen, whose business it is to go over the stretch of road assigned to them a certain number of times each day and night; and various methods of checking and controlling the men in the faithful performance of this important duty are in vogue. On the Continent of Europe those portions of the road beyond the control of the guards are fenced in, to prevent access thereto of men or animals. Such provision is especially necessary at stations. In the United States, save in a few exceptional cases, and in these only upon limited sections of track, such elaborate provisions for guarding the roadway are not possible, for a number of reasons; the chief among these are that railway companies have not such absolute control over their roadway as is the case in European countries, and that on the score of expense the great length of many of them would preclude such supervision.

9. Stations.

To afford the necessary facilities for the rapid and convenient reception and discharge of goods and passengers, as well as to provide for the necessary renewal or increase of the motive-power required to move the trains, stations are established. They serve, further, as convenient *foci* for the distribution of traffic by other modes of communication—by roads, canals, rivers, and the sea.

Classes of Stations.—According to their location, stations are distinguished as terminal or intermediate stations. The necessity of dividing the passenger from the freight traffic has caused suitable provision to be made at terminal stations for the management of these two forms of traffic; so that the terminal station comprises a passenger station and a freight station. Furthermore, as provision must be made for the temporary shelter and the repair of locomotives and cars, such terminal stations, and to some extent, also, the intermediate stations, in proportion to their importance, are provided with round-houses for the locomotives, car-sheds for the housing and cleaning of cars, and repair-shops for the repair of both.

Location of Stations.—The location of passenger and freight stations will be governed largely by circumstances in which convenience and economy are the principal considerations; not infrequently they are situated some distance apart. The passenger stations at the termini of the road, providing, as they do, the natural termini, are placed necessarily on the main line, and wherever it is possible are situated near to the centre of population from which the traffic is derived. The freight station need not be situated directly on the main line, but may be, and often is, placed on a branch, some distance beyond or short of the passenger station. To provide for extension of terminal-station facilities which the increase of passenger and freight traffic will necessitate from time to time, ample space should be set apart, when the station is planned, to permit of its expansion. In large and rapidly-growing cities, especially in the United States, such provision is imperative. Of late there has been a tendency to concentrate the terminal facilities (especially for foreign traffic) in large cities in one extensive station-building, and, where circumstances of location render it convenient to do so, to provide for the exchange and transfer of freight from one road to another by means of a "belt road" communicating with the tracks of all the roads entering the city.

Terminal Stations.—The proper planning of a terminal station with reference to the convenience of arriving and departing trains and passengers, and to the connection of tracks, by means of switches (*pl.* 28, *figs.* 1, 3), to permit of the speedy shifting of assembling trains from one track to another, will exercise a very important influence on the economical and efficient despatch of the business of the road. While the plan of construction will differ materially according to the availability of the location, the following notes may serve to indicate the general requirements of a large station.

Arrangement of Terminal Stations.—The approaches and yard, or court, of passenger stations should be of generous area, to permit of the entrance and egress of vehicles. The following rooms should be provided (*fig.* 4): a spacious hall about the centre of the building, with ticket-office (middle) and baggage-room (right), and several waiting-rooms (left), with restaurant (between the two), ladies' room and toilet-rooms (left), station-master's bureau and telegraph-offices (in the right division), and apartments for officials and other employés on duty. Figures 2*a* and 2*b* exhibit elevation and ground-plan of the station at Stuttgart, one of the most complete in Germany. The terminal stations are completely roofed (*fig.* 5); and elaborate structures of this kind are to be found in London (*pl.* 4, *fig.* 28), Paris, Berlin, Frankfort (*pl.* 29, *fig.* 1), and in a number of American cities; these structures are entitled to rank as architectural masterpieces (*figs.* 1–3). In Figure 2*b* (*pl.* 28) the separation of the arrival-and-departure tracks by their disposition on the opposite sides of the station-house is shown as a typical example.

The Victoria Terminal Buildings of the Great Indian Peninsula Railway, at Bombay, the second city in the Indian empire, are believed to constitute the most extensive structure of the kind in the world. The total length of the front or west façade is over 1500 feet. The style of architecture adopted is a free treatment of Venetian Gothic with an Oriental feeling. The main feature of the edifice is the large octagonal dome that crowns the grand central staircase of the administrative offices. It is of solid cut-stone masonry, pierced by eight lancet-shaped two-light windows of stained glass of ornate design. A colossal stone figure of *Progress*, 16½ feet in height, surmounts the apex of the dome, and the principal gables are crowned with groups of sculpture. Under a canopy, below the large clock of the central gable, is placed a beautiful statue of Her Majesty the queen-empress. The interior of the structure has been skilfully arranged and artistically finished, colored polished marbles and granites being used in the halls, waiting-, and refreshment-rooms with pleasing effect. The entire work, to complete which required ten years, was executed by native workmen, under the supervision of F. W. Stevens, F. R. I., the architect, and the cost was twenty-seven lacs of rupees (nearly $19,000,000). The buildings (*pl.* 29, *fig.* 2) were opened in May, 1888.

The New Central Railway-station at Frankfort-on-the-Main, which has recently been opened for traffic, is one of the most imposing structures of modern times, both in dimension and in detail (*fig.* 1). It is a fire-proof edifice of Heilbronn sandstone, and is a beautiful example of the Renaissance style of architecture. The great width of the building (721½ feet) gives to it the effect of comparative lowness, but the artistic disposition of the entrances and pavilions and the sculptured adornments impart an impressive grandeur to the whole design. The central entrance to the station projects considerably in advance of the rest of the building-line, and by its distinct membering stands out conspicuously from the whole. This part of the structure contains the ticket-offices, telegraph-offices, and baggage and police departments. Corner pavilions and protruding portals of peculiar construction and the great round-arched windows enliven the aspect of the wings. The corner pavilion (to the left in the view) contains the so-called "imperial apartments," for the reception of royal travellers; on the opposite side are the meeting-hall and reception-rooms of the managers of the different railway lines entering the dépôt. On the right and left of the main vestibule, lobbies with arched roofs lead to the waiting- and dining-rooms, the ladies' rooms, the imperial apartments, the meeting-halls above mentioned, and the toilet-rooms. The main entrance-hall leads directly to the middle platform of the train-shed (*pl.* 5, *fig.* 1), which consists of three naves, for the reception of the six railway lines, and is covered with an iron roof of three low-arched spans. This train-hall has a length of 610 feet and a width of 551 feet, and the height of the naves to the centre of the spans is 93½ feet. In each wing also is a vestibule leading to the middle platform of the great train-hall. The exterior of the wing vestibules resembles in style the architecture of the central entrance, only their arches are smaller. The building was erected by Engineer Frantz from the plans of Inspector Eggert, who was in charge. The foundation was begun in 1881, and the superstructure in 1883. The cost of the building was about eight million five hundred thousand dollars; it is heated by steam and lighted by electricity throughout.

The Terminal Passenger Station of the Pennsylvania Railroad at Philadelphia (*pl.* 29, *fig.* 3) is a fine structure of red brick and terra-cotta. While of less imposing dimensions than the Frankfort station, above noticed, it is no less picturesque and effective in outline, the style of architecture approaching Gothic in sentiment. The interior arrangement of the building is well planned and answers the requirements of its intended use as the terminus of an elevated railway. The entrances, ticket-, telegraph-, and baggage-offices are on the ground-floor; the ladies' retiring-rooms, restaurant, and waiting-room are on the second floor, communicating with the train-hall. The latter is provided with two single- and three double-track sections, and is covered by an arched iron roof in two spans of graceful design. To meet the increasing demands of the passenger traffic, a large addition to the present station is projected.

Intermediate Stations.—For intermediate stations it is usual to throw a roof, supported on pillars or otherwise, over the platform (*pl.* 28, *fig.* 6), for the better protection of passengers. Figures 7*a* and 7*b*, show elevation and ground-plan of a small intermediate station. Figures 15*a* and 15*b* represent a specimen watchman's house in elevation and ground-plan in use on the Alteneck-Halzminden Railway.

Freight Stations.—The freight station commonly takes the form of a long building with a platform or footway at the height of the floor of the cars, with doors on both sides, and a projecting roof for the protection of wagons. Platforms are arranged along the entire length of the building for loading and unloading at any point (*fig.* 8) For stations where a large freight business is conducted, the plan of loading and unloading through the side-doors is found insufficient, and in such cases large covered areas lighted from above are made use of. The freight tracks, passages for the entrance and egress of vehicles, and platforms are here all protected, and the loading and unloading of freight may be effected under cover. The handling of the freight is done either by hand or by steam or hydraulic power. A notable example is the freight station of the Pennsylvania Railroad at the Philadelphia terminus, where a number of hydraulic elevators are employed to lift the goods from the ground-floor of the structure to the level of the elevated roadway; by the same means, goods unloaded from the cars are lowered to the ground-floor of the building. As the freight stations must necessarily be used to some extent as dépôts or storehouses for goods, as well as for their reception in transit from wagons to rail, and *vice versa*, it is important in planning them that ample floor-space should be provided to serve this purpose. To avoid overcrowding, the management of many railway corporations assume, directly or indirectly, the responsibility of delivering goods to their local destination.

The Express System is universally in use in the United States for the forwarding of small parcels and packages. This service is performed by "express companies" controlled by or affiliated with the railway management. The express companies call for the goods, transport them by fast trains, and deliver them to their respective owners at the points of destination. The business of these companies is of enormous proportions, and where packages of moderate dimensions and of considerable value are to be transported by rail, and especially where a prompt delivery is desirable, they are forwarded by express rather than by the slower freight service.

Round-houses.—At the terminal stations and at intermediate stations (say ten or twenty miles apart) are round-houses, or buildings for the reception and housing of the reserved engines. The location of these houses is chosen with the view of providing as promptly as possible ample motive-power where it will be most needed. The main-track connection is made either by turntables (the most common method; *pl.* 31, *fig.* 1), by transfer-tables (*pl.* 28, *fig.* 14), or by switches. The ground-plan of these houses varies according to the mode of transfer adopted. Where turntables are used, as is the almost universal practice in the United States, the plan may be circular, semicircular, horseshoe-shaped, or polygonal (*fig.* 9*a*). The tracks radiate from the turntable placed at the centre (*fig.* 9*b*). When the transfer-table is employed, the building has a rectangular form; the stands for the engines are placed side by side, and are connected with the main tracks by means of the shifting-tracks. This form of construction is less costly than the other, and has certain advantages in respect to operation where a large number of engines are assembled. In all cases proper provision is made by means of fireproof ash-pits for drawing the fires of the engines.

Watering-stations for supplying the engines with water are established along the line of the road at frequent intervals, and invariably in connection with the engine-houses. The source of supply is a convenient spring or an adjacent watercourse. On the upper floor are two iron or wooden cisterns, and on the ground-floor are the heating apparatus and the pump, communicating with the tanks by tubes, to maintain a circulation of the water. The pump may be actuated by steam-power or by a windmill. Figure 10 represents a water-station as commonly arranged. The locomotive-tender is filled directly from the reservoir by a hose-pipe connection controlled by a suitable valve and hinged or jointed in such a manner that it may be raised out of the way or lowered, as may be necessary, or more elaborate fixtures for the same purpose are provided (*figs.* 11, 12).

Car-sheds.—For the protection of the rolling-stock from unnecessary exposure to the weather, car-sheds are provided at all main stations, under which the passenger-cars are housed when they are not in service.

Repair-shops.—The constant wear and tear to which the rolling-stock is subjected renders it necessary to provide facilities for the repair and renovation of engines and cars. Upon roads of considerable length and heavy traffic, a number of these are required. These establishments should be supplied with a complete plant for working in metals and wood. This will embrace general machine-shops, examining- or inspection-shops, departments for founding, forging, wheelwrighting, etc., brass-founding and coppersmithing, woodworking department—embracing cabinet-working and upholstering and paint-shop—storage for lumber and other material and for stock of interchangeable parts, offices, etc.

10. Railway-cars.

Early Railway-cars.—That the railway-cars (carriages, coupés) may be able to travel over the railway with safety at the high speed required in railway practice, they should be built with greater solidity than the road-vehicles previously described (p. 164), and upon a different model. The earliest railway-cars resembled the ordinary road-wagon in the fact that the wheels turned free upon the axles, and to prevent the wheels from leaving the track they were guided by flanges on the rail (*pl.* 22, *fig.* 4). With the introduction of the edge-rail (*fig.* 5), some fifty years later, cast-iron flanged wheels came into use, and it is now the universal practice to fasten the wheels immovably to the axles, so that they may revolve together. In Europe the general practice is to attach the pedestals of the axle-boxes directly to the bed of the car (*pl.* 30, *fig.* 5). In America the custom is to mount the car-body independently on wheel-trucks (*pl.* 31, *fig.* 2). This variation is explained by the difference in the length and weight of the cars, the European small and comparatively light vehicles (*pl.* 30, *fig.* 16) being in marked contrast with the long and heavy cars used on American roads (*pl.* 32, *fig.* 5). The number of wheels on which the car is borne will vary with the size and weight of the car. The earliest railway-cars were placed upon four wheels (*pl.* 23, *fig.* 5), and this remained the general practice in Europe, where the small and light compartment-carriages are still almost universally in vogue (*pl.* 30, *fig.* 16), down to a comparatively recent date, when, with the gradual increase of the length and weight of the rolling-stock, the six-wheel system on three axles (*fig.* 14) has come into general use, as is notably the case on the English railways.

American System of Mounting on Trucks.—The usual American practice is to support the car-body on two four-wheeled trucks placed respectively under the front and rear part of the car, the axles of each truck being placed close together (*pl.* 32, *fig.* 5). The principal feature of this form of support is that the connection between the truck and the car-body is not rigid (as where the axle-boxes on pedestals are attached directly to the car-frame), but is flexible, permitting the truck to turn, or swivel, beneath the car-bed as the car strikes a curve, this freedom of motion to a large extent relieving the car of jar and shock. This swivelling feature is obtained by means of a mechanical device similar in principle to that employed to give the swivelling movement to the front axle of the common road-vehicle. It is shown on Plate 31 (*fig.* 2), which represents a longitudinal view and a transverse section of an American passenger-car truck. It consists of a strong timber frame to which the wheels are suitably attached; inside of this frame is a so-called "swinging-bolster," resting on elliptic springs. This bolster carries a centre-casting, which forms the bushing for the kingbolt, and for what may be called (by reason of its resemblance to the corresponding device upon the common road-vehicle) a "fifth wheel." Upon this the end of the car oscillates. On the same principle, parlor and hotel cars on American railways are constructed with twelve (*pl.* 32, *fig.* 5), and even with sixteen, wheels (*pl.* 30, *fig.* 17). The best class of passenger-cars on American railways are now placed on two six-wheeled trucks (*pl.* 32, *figs.* 4, 5).

Car-wheels.—At first it was the practice to give the tread of the wheels a cylindrical form, but it was soon observed that this form permitted too much lateral play between the flanges and the rails, and resort was had to the conical form, now universally in use (*pl.* 30, *figs.* 1–4). This construction not only corrects the above-named defect, but also lessens to some extent the resistance in passing curves, inasmuch as by centrifugal force the outer wheel on the curve mounts the rail and describes a larger circle than the inner one. The car-wheel and axle, which are made in many different ways, constitute the most important parts of the structure of the rolling-stock of a railway. Cast iron is largely used in the construction of the wheel, which may be either the spoke- or the disk-wheel. A form of the latter which is much used is seen in Figures 1 and 2. Figure 1 is the well-known Washburn wheel. It is a cast wheel having an arch in its central part, said arch being joined to the rim by a curved web. Where the web joins the rim, the disk is strengthened by a series of curved ribs.

Chilled Wheels.—The most approved system of making cast-iron wheels is that in which the body of the wheel is allowed to cool slowly, so as to retain as much of its toughness as possible, while the rim, which is subject to wear, is made as hard as possible by various methods of rapid cooling called "chilling." The chilled cast-iron wheel is in common use in the United States on both passenger- and freight-cars.

Composite Wheels.—Wheels constructed in part of wrought iron are well adapted for their intended service. The earliest forms of composite wheels were those of Stephenson and Losh (1816). In these, the spokes were made of wrought iron, and the hub and rim were cast upon them. A wrought-iron tire was then shrunk upon the rim, and secured in place by a dove-tail channel cast in the rim, or other convenient artifice. A wheel of this pattern is shown in Figure 3. When the tire is in place, the periphery of the wheel is turned down to the proper dimensions in the lathe. Disk-wheels (*figs.* 1, 2, 4) have almost entirely superseded the spoke-wheels, as they afford a more uniform support to the wearing-surface of the wheel. The diameter of the wheels in use on American railways varies from 30 to 33 inches for passenger- and freight-cars, and from 26 to 28 inches for coal-cars. This measurement is the least diameter from tread to tread. Respecting the wear of the chilled wheel in general use in the United States, Trautwine gives fifty thousand miles as the average run.

Paper Wheels.—An interesting novelty in construction which has lately attracted attention is the use, with composite wheels, of wood and paper as a packing between tires and hubs, to absorb jar (*pl.* 31, *fig.* 15). The so-called "paper car-wheel" is formed of a cast-iron or steel hub and a tire of rolled steel, in the centre or main body, of which straw-board is tightly pressed as a packing between two circular plates of rolled iron, which are very strongly secured by bolts. Paper wheels have come largely into use on locomotive-trucks and on passenger-, parlor-, and sleeping-cars, and have made an unusually good record in practice. Some allowance should be made, however, as Trautwine says in speaking of their wearing qualities, for the fact that they are used principally under the best class of passenger-cars on through trains that make few stops; hence they are subjected to less of the destructive action of the brakes than the common wheels. The greater number of the latter, furthermore, are running under freight-cars, where they are subject to the hardest kind of usage, not only on account of the frequent stops, but also on account of the inferior character of the springs in use with cars of this class.

Steel Tires.—The material of the tires, where compound wheels are used, is commonly steel—a material which, notwithstanding its greater cost, demonstrates its value by much greater durability in service than the common chilled cast-iron wheels. Compound wheels of cast and wrought iron with steel tires are coming into general use under first-class passenger-cars. The modifications in form and construction are numerous.

Car-axles are constructed of wrought iron or steel, with the wheels of the cars fastened to them by shrinking or pressing, so that they may better withstand the strain to which they are exposed by the lateral movements of the car in swinging around curves or by reason of irregularities of the roadway. The appearance of the car-axle is shown in Figure 3 (*pl.* 31). The severe torsional strain to which the axle, made of a single piece, with the wheels firmly attached to it, is exposed in turning curves has caused the invention of many ingenious artifices to obviate the difficulty, but none have come into general use. The axles run in bearings of metal made of anti-friction compositions of various kinds. The bearings, in turn, are contained in so-called "axle-boxes," which contain, likewise, the various contrivances employed for lubrication. The axle-boxes vary greatly in details of construction, but should be as simple as possible, and should afford proper protection against the entrance of dust and grit and against the loss of lubricants, and should be readily accessible for examination.

Car-springs.—The axles bear the entire weight of the car, and, that the jar of the wheel shall not be transmitted directly to the car, it is the universal practice to interpose some elastic or yielding material between the car and the axle, to receive the shock and moderate its effect. For this purpose springs of a great variety of form are employed (*figs.* 7–11), cast steel and rubber being the materials commonly selected. Figure 5 (*pl.* 30) exhibits a method of supporting the car-body upon springs in the absence of trucks, the provision for the vertical play of the spring being very clearly shown. Figure 6 exhibits another device for securing the frame to the ends of the springs to insure the requisite flexibility of the combination. Figure 13*a* shows a double-spring system employed on German railway passenger-carriages, on which one set of springs is placed between the longitudinal supporting frame of the carriage and the axle, and the other between the frame and the carriage-body. In American practice, in which, as previously noted, the car-body rests upon trucks, it is the custom to interpose two sets of springs between the car and the axle. This is shown on Plate 31 (*fig.* 2*b*), from which it will be observed that the end of the car rests upon the swinging bolster, beneath which are elliptical springs, the entire weight being suspended from a frame which, in turn, rests upon springs of india-rubber carried on a so-called "equalizing-bar," whose ends rest on the axle-boxes. Figure 7 (*pl.* 30) exhibits certain details of the running-gear and Figure 12 the under-frame of the car-body of German railway-carriages.

Car-couplings.—To connect the cars of a train with one another and with the engine, a coupling of some form must be employed. The simplest form of this device, the link and coupling-pin attached to a draw-bar, is in common use in the United States. In Europe there is employed a more rigid form of coupling, a view of which is shown in Figure 10. This is the so-called "screw-coupling," consisting of a right- and left-handed screw shackle, by which a coupling can be made as rigid as may be desired. The draw-bar, passing beneath the car-frame, is connected to a spring of some form, which lessens the jolt of the sudden starting of the train. When the train stops, each car, by reason of its momentum, tends to push up against the one in front of it, and in case of sudden stoppage for any reason the shock of the cars butting against one another would severely strain the inelastic frame of these vehicles, were it not that each car is provided with elastic buffers to receive these frequent shocks. Both these devices—buffing- and drawing-springs—are made sufficiently clear in Figure 7. Figures 8 and 9 exhibit modifications of the buffer-spring, the first (*fig.* 8) having a special spring of hardened steel and the second (*fig.* 9) one of rubber, in which rubber rings alternating with brass disks form an air-cushion which yields with the slightest pressure. As an additional precaution against the breaking of a coupling, guard-chains, which ordinarily hang slack, are sometimes provided between the cars. These chains are of somewhat doubtful utility, as the shock that would break the ordinary coupling would be more than likely to snap the chains.

Safety-couplings.—In order to effect the coupling of the cars by the devices here described, the train-hands must step between the cars—a practice that is attended with much danger, and that is accountable for more fatal accidents than any other single cause. To avoid this danger, many devices have been proposed for coupling cars from the platform and by appliances working automatically. Some of these are exceedingly ingenious, and to some extent have been utilized. The want of uniformity in the construction of cars, especially those for freight service, has thus far proved a great hindrance to the general adoption of safety-devices of this kind. On Plate 31 (*figs.* 4–6) is shown the Janney coupling, adopted by the Pennsylvania Railroad, and in general use on other American railways.

Brakes.—To stop a train at stations or elsewhere, to diminish its speed in descending a grade, or to bring it quickly to a stop in case of danger, some form of brake mechanism is necessary. It is a mistake to suppose that the ideally perfect brake is one that will bring a moving train to a standstill instantaneously. Such a mechanism would be utterly unavailable even were it possible to realize it in practice. It must be borne in mind that the *vis viva* of the moving car cannot be overcome without the expenditure of a corresponding opposing force. If the wheels of the moving car are arrested suddenly, the entire train will slide upon the rails until friction brings it to rest; or if sliding be prevented, the result will be a shock substantially like that caused by the collision of two trains, with the same destructive effect upon cars, passengers, and freight. The efficient brake, therefore, is the one that will stop the train quickly, but not instantly.

Hand-brakes.—The ordinary hand-brake (once universally in use, but now discarded on nearly all passenger-trains in American railway practice in favor of the far more efficient power-brake) is commonly placed upon both ends of the car, and is operated by the guard or brakeman from the car-platform or the roof. It acts on the principle of applying pressure by means of a brake-block of wood or iron to the periphery of the wheels. For this purpose a brake-wheel or lever is placed on the front and rear platform, by the rotation of which a chain is wound up or a combination of rods, levers, etc., is actuated, by means of which the brake-blocks are forcibly pressed against the wheels. One form of the hand-brake is shown on Plate 30 (*fig.* 11). The operative mechanism is sometimes a screw, but more commonly a chain the tension of which is maintained by the intervention of a pawl and ratchet. The forms of braking devices are nearly as numerous as those of car-couplings. The subject may be disposed of, however, by the statement that the most perfect system yet devised is the continuous brake applied by the engine-driver from his cab. Several plans of this order have been proposed, the actuating power being compressed air, vacuum (atmospheric pressure), and fluid pressure.

Power-brakes.—The continuous-brake system worked by compressed air, devised and perfected by George Westinghouse, Jr., of Pittsburg, Pa., has been by far the most successful, and is now everywhere in use in the United States on passenger-trains, and is rapidly being introduced on European roads. One of the special merits of the Westinghouse system is that it is not only continuous—that is, capable of being operated from a single point throughout the entire train—but also automatic. Normally, the pressure of the air in a continuous pipe and reservoirs beneath each car of the train keeps the brakes off. When it is desired to apply the brakes, the air-pressure must be reduced, when a valve of peculiar construction is brought into action and effects the application of the brake. To release the brakes, the engine-driver must restore the pressure in the brake-pipe. From this explanation it will be observed that in the event of an accident by which the brake-pipe is broken—as, for example, by the parting of one or several cars of a train—the escape of the air would reduce the pressure, and the brakes would be applied at once, automatically. The efficiency of the air-brake may be duly estimated by considering that, with its use, a train travelling at the highest attainable speed may be stopped within its own length. Its general adoption by railway managers has contributed more to the safety of railway travel than any other single invention.

The application of the Westinghouse continuous-brake system is exhibited on Plates 31 and 32. Figure 16 (*pl.* 31) shows the disposition of the operating mechanism upon the locomotive and the mode of applying the brake to the periphery of the driving-wheels, and Figures 2 to 5 (*pl.* 32) show the attachment of the brake mechanism beneath the car-body of the standard rolling-stock of the Pennsylvania Railroad. Mr. Westinghouse has recently succeeded in adapting his brake to the requirements of freight service, and it is not unlikely, from present indications, that a few years will see its general introduction upon this important branch of the railway service. For the mechanical details of construction and operation reference may be made to the volume on Mechanics.

English and American Car Systems.—With reference to the internal arrangements, division of the seats, etc., of railway-cars for passenger service, two systems are in vogue—namely, the English, or coupé, system, of comparatively small and light carriages (*pl.* 30, *figs.* 12, 14, 16), in which the passengers enter and leave the carriage by doors provided at the sides and occupy small compartments separated from one another by partitions; and the American, or intercommunicating, system (*figs.* 13, 15, 17, 18), in which the passengers enter and leave the car at the front and the rear, and where the seats are disposed on the right and the left of a passage-way running the whole length of the car.

English Compartment-carriage.—The advantages claimed for the English or compartment system, generally in use in Europe (*fig.* 16), are the following: Privacy and freedom from disturbance, the exclusive reservation of compartments for ladies, greater protection against draughts, quicker filling and emptying of trains, greater handiness in making up trains of smaller carriages, and corresponding saving of labor at main stations. On the other hand, the system has the disadvantages of greater danger in entering and in leaving the carriage, discomfort to those occupying the middle seats, and to the entire coupé in hot weather, isolation of the traveller, by which communication with the guards or train officials and with the occupants of adjoining compartments is prevented, danger from the side doors, which weaken the carriage-body by reason of their presence, and the greater length of the train.

American Car.—As special advantages the following claims are made in behalf of the American system: Freedom of entrance and exit, and of communication at all times with the train officials and passengers, the convenience of retiring-rooms, good lighting, ventilation in hot weather, safety of the passengers from assault with intent to plunder or murder, the convenience to the train-hands in passing from car to car, and lessened liability to derailment, by reason of greater weight, and to destruction in case of derailment, by reason of more substantial construction. It is urged against the American railway-car that passengers are more subject to be disturbed, and that more labor is involved in making up trains.

American Car System in Europe.—There has been much controversy over the relative merits and demerits of these diverse types of vehicle, but, in spite of the tenacity with which the English especially cling to the established order, the fact remains that the American railway-car is every year coming into more general use on European railways. The American parlor-car (*pl.* 33, *fig.* 1) and sleeping-car (*fig.* 3) are so greatly superior in convenience and comfort to anything in vogue on European railways that their adoption has of late years become very general. The gradual drift in the direction of the American plan of arrangement is shown also in the introduction of mixed or composite carriages, in which the effort has been to combine the features of both systems—the exclusiveness of the compartment plan with the freedom of entrance and egress and of communication of the American car. In these composite structures the carriage is divided, as usual, into several compartments placed in communication by doors in the middle of the carriage, the entrance and exit doors being at the front and the rear (*pl.* 30, *fig.* 13*b*).

European "Class" Cars.—The railway-carriages on European roads are divided into three, and occasionally four, classes, differing in respect of the comfort and convenience they afford the travelling public. The fourth-class conveyance (which is rarely seen) has no seats of any kind, the passengers being obliged to stand; it is closed, has windows, and at most two doors. At night, lamps are provided. Such cars are used to convey laborers to and from work. The third-class carriages on the Continent, as a rule, have plain unupholstered seats with wooden backs reaching usually to the height of the shoulders (*fig.* 16). The entrance and exit doors are at the sides, as in the first- and second-class carriages. In England, until recently, the third-class carriages were even less comfortable, but of late they have been notably improved. The earliest first-class carriages of English roads were 15 feet long, 6½ feet wide, 4¾ feet high, and weighed three and one-fourth tons. They were divided into three compartments, each compartment accommodating six persons, or eighteen in all. Now they are built 20 or 30 feet long and from 8 to 8½ feet wide, and weigh from eight to thirteen tons. The modern first-class English carriage has four compartments (*fig.* 16), and those of the second and third class usually five. The tendency in England, especially, has been for some time in the direction of increasing the length and the weight of the carriages.

German Cars.—On German roads, the carriages of the second class are comfortably upholstered, provided with floor-coverings, racks for holding parcels, etc., and are warmed in cold weather, and otherwise made so comfortable to the traveller that only a comparatively small proportion of the public travel by first-class conveyance. In England, on the other hand, until within ten years or so, the second-class carriages were destitute of upholstering and offered about the same conveniences as the German third-class carriages. Of late years English cars have been notably improved. The first-class carriage of the German railway differs from the second-class chiefly in being more roomy and more expensively fitted up and cushioned. On the French, Belgian, and English roads, as a rule, the first-class carriages are the only ones that afford proper conveniences for the comfort of the better class of the travelling public.

Parlor-cars.—The recent introduction of the American palace- or parlor-cars (*pl.* 32, *figs.* 4, 6; *pl.* 33, *figs.* 1, 3), the luxurious fittings and easy riding of which are much superior to those of the compartment carriages, has doubtless had much to do with raising the standard of comfortable railway travel in most European countries. The great distances covered by American railway lines have rendered it desirable to make special provision for the comfort and convenience of the travelling public, and this fact explains the origin and development of these luxuriously-appointed conveyances, with which all the important lines of railways in the United States are at present provided, and which make railway travelling in this country not simply endurable, but enjoyable. The modern American parlor-cars of Pullman (*pl.* 32, *fig.* 4), Woodruff, Wagner, Mann, and other builders whose names are familiar to the American travelling public, with their elaborate conveniences for comfortable travelling and for sleeping and eating *en route* (*pl.* 30, *figs.* 17, 18; *pl.* 33, *figs.* 1–4), are so far in advance of the practice of other countries that no comparison is possible.

As an instructive illustration typical of the best practice attained in the passenger service of American railways, reference is made to Plate 32 (*figs.* 1–5), which gives an excellent impression of the appearance of a locomotive and the cars of a train of the best class as represented by the service of the Pennsylvania Railroad. One of the latest improvements is the "vestibule car" (*fig.* 6). In this the ends of the cars are coupled in such manner that the passageway from one to another is entirely enclosed, the projecting portion of the connection being made flexible, to adapt itself to the swinging of the cars around curves, etc. These vestibuled cars have lately come into use upon through trains for fast passenger-service.

Car-heating.—For heating the passenger-cars various plans are in vogue. These comprise the use of stoves, hot-water cylinders, specially prepared slow-burning wood-charcoal in sheet-metal cases placed under the seats, various systems of steam-circulation, etc. Where stoves are used, as is the custom on American railways, they are either placed at the ends of the car or suspended beneath the under-frame. The stoves are jacketted, leaving an annular space between the inner and outer shells. A pipe capped with a valved cowl communicates with this air-space and automatically adjusts itself so as to induce a constant current of air. This, being heated on its passage through the air-space of the stove, is distributed by pipes or other channels carried along the sides of the car and furnished with openings at proper intervals. The escape of the heated air may be provided for by a cowl placed on top of the car, which automatically sets its flaring mouth in a direction opposite to that in which the car is moving, or by adjustable ventilating panels of glass placed along the upper part of the car beneath a raised central section of the roof, and by other simple artifices. Heaters constructed substantially on the same principle as stoves and designed to effect the warming of the train by a connected system of hot-air pipes have been devised, but have not come into general use.

The much greater distances traversed by American railroads, and the greater severity of the American winters as compared with European climatic conditions, make the problem of heating the passenger-trains of much greater importance. The employment of stoves for this service has the grave objection of danger from fire in the event of an accident by which the cars may be overturned and the passengers imprisoned. The recent occurrence of several distressing accidents on American railways, in which the lives of many passengers have been destroyed by fire communicated to the woodwork from the car stoves, has caused the enactment of laws by the legislatures of several States forbidding the use of stoves for car-heating. The result has been that many plans for employing steam for train-heating have been tried, with varying success. Thus far, however, no system has been devised that entirely meets the requirements of practice.

Car-lighting.—For lighting the cars and carriages, lamps burning heavy oils, mineral or animal, are employed to a considerable extent. On the better class of roads in Europe and America these have been discarded in favor of gas. For this purpose common coal-gas is compressed in cylinders carried under the car, each containing a sufficient supply of gas to serve for lighting the car a number of hours. Recently, on the best class of American cars, the system of incandescent electric lighting has been introduced with very satisfactory results, the electric current being furnished from a supply of secondary batteries or accumulators. Present indications are that the electric system of train-lighting will come ultimately into general use.

Baggage-cars.—For the transportation of the baggage (*Anglicè*, luggage) the practice on American railways provides the train with a car usually left open or free inside and furnished with sliding-doors at the sides, after the fashion of the freight-car, for the convenient taking-on, stowing, and delivery of trunks and similar articles. Sometimes only a portion of a car is set apart for this purpose, the other part being used for passengers, a suitable partition dividing the car into two compartments. The English "luggage brake-van," which may stand as the type of the vehicles in use on the European railways, has side-doors and is free inside for the reception of the passengers' luggage. It is sometimes provided with a small enclosure from side to side having doors in the ends, and having, furthermore, projecting sides furnished with windows, through which the guard may have a view of the entire train. Occasionally a passenger-carriage is divided, one compartment being for the guard and the other for the luggage of the passengers.

Postal-cars.—For the postal service special cars with elaborate conveniences for the expeditious handling, sorting, and delivery of mail-matter along the route are provided, making them, in fact, travelling post-offices. Ingenious devices are employed in certain cases for taking on mail-matter while the train is running at high speed. Figure 23 (*pl.* 30) shows a plan of this kind adopted in England and Germany, where the mail-pouch, suspended from a horizontal arm at the proper height and distance from the track, is swept off by the passing cord of a pivoted catch-basket, let down for the purpose; after the contents of the basket are taken into the postal-car through an opening in the side of the car, the basket is thrown up against the side of the car, out of the way. Figure 3 (*pl.* 32) exhibits an American postal-car in use on the Pennsylvania Railroad. The mail-bag-catching apparatus is a pivoted bent iron bar attached to door of the car.

Freight-cars.—The earliest forms of cars for carrying freight were simple platforms mounted on four wheels with sides raised from 5 to 10 inches. To meet the requirements of the service, these were followed by the adoption of a pattern in which, as circumstances required, the sides and ends could be raised by the addition of panels fitted in place and held by simple fastenings; the goods, for protection from wind, rain, and dust, were covered with oiled canvas (tarpaulins). Later, enclosed wagons or box-cars (*pl.* 30, *fig.* 21) with sliding-doors at the sides, to permit of running close up to the station platform to take on and discharge goods, have been employed, and these are now in almost universal use in all countries for freight conveyance, except for the transportation of coal, ores, quarry-stone, and crude products of a character that will not suffer from exposure. For the conveyance of cattle, open or crib cars are provided, which in later constructions are furnished with means for feeding and watering the animals in transit. For valuable animals padded stalls are provided. For the transportation of perishable materials, dressed meat, fruit, and the like, special refrigerator-cars supplied with means for maintaining a low temperature are extensively used on American railways.

Cars for Crude Freight.—For the conveyance of crude materials (coal, ores, building-stone, etc.) open cars are employed, which may be either simple platform- or "gondola-cars," low- or high-sided. The coal-wagons are occasionally supplied with hinged bottoms or sides, for greater convenience in discharging the load. Open cars of the pattern here referred to, in use on European railways, are shown in Figures 19, 20, and 22, the last exhibiting the convenience with which hoisting devices may be applied for loading and unloading.

Express-cars.—Upon the railways of the United States, where there is an enormous traffic in the more valuable classes of goods which demand rapid conveyance by the so-called "express companies" (p. 213), a class of enclosed cars of the general type of a baggage-car, but of much more substantial and generally superior construction, is employed (*pl.* 32, *fig.* 2).

Snow-ploughs.—To clear the tracks of snow, which is often a serious hindrance to traffic on railroads in America, where climatic conditions are more severe than throughout the greater part of Europe, snow-ploughs are used (*pl.* 30, *fig.* 24). These are constructed commonly on the plan of a wedge-shaped framework of iron, which is pushed in advance of the locomotive, so as to divide the snow and throw it on each side of the track. To prevent the filling up of cuts, various devices, such as hedges, earth embankments, fences, and occasionally walls of masonry, are resorted to. The more northerly of the several great transcontinental railways of the United States are specially exposed to obstruction from snow in those parts of their routes that cross the great mountain-ranges. To guard against the interruptions from this source, many miles of snow-sheds (*pl.* 34, *fig.* 2) have been built along those portions of the track that are most exposed. These sheds are designed for the purpose of sheltering the track from the frequent snow-slides and drifts by directing the moving snow over and beyond the track.

11. SIGNALS.

Signals are used to indicate to the station-officials and others on duty what is taking place on the road, that they may be able to communicate to the engine-drivers, by means of the code, such information and instructions as may be necessary to insure the safety of trains, etc.

Classes of Signals.—The signals employed may be optical or acoustical, for it is only through the senses of sight and hearing that rapid and sharply-defined impressions may be received. The signals, of whatever nature they may be, are transmitted by repetition. Inasmuch, however, as the acoustic signals are audible for only a limited distance, and as optical signals, under unfavorable atmospheric conditions, cannot be distinguished very far, electricity has come to be used exclusively as the means of transmitting signals over considerable distances.

Stephenson's Signal System.—The first railway opened for traffic, in 1829, between Manchester and Liverpool, had no other provision for signalling than that afforded by the steam-whistle of the locomotive. The first step toward the invention of a signal system was made somewhat later by Stephenson, who introduced, at the entrance and exit places of the stations and at curves, posts upon which were mounted disks with the opposite faces of different colors. These disks could be shifted, and at night were replaced by lanterns of distinct colors.

The "Semaphore" Signal.—The Stephenson system remained in use until the year 1841, when the English engineer Gregory introduced the "semaphore" signal, based upon the old system of telegraphing over short distances. For fixed signalling, this system, with numerous modifications in the mode of operation, is in universal use on railways at the present day. The semaphore has two arms, for trains coming from either direction, and the position of the arms, whether vertical or inclined at an obtuse or acute angle, determines, according to a prearranged code, the character of the signal to be conveyed to the engine-driver of an approaching train. At night the semaphores or disks are illuminated by suitable lamps, by means of which lights of different colors (commonly red and green, signifying respectively *danger* and *caution*) are exhibited.

A recent improvement of the semaphore, which is the best position signal yet devised, is a modification invented by Koyl, an American engineer, which may be used by night, as well as by day, in the same manner (*pl.* 25, *figs.* 1, 2). A reflector of silvered glass is placed along the centre of the semaphore arm from end to end; but, as it would be impossible to illuminate a flat reflector with an ordinary lamp sufficiently for railway purposes, the flat semaphore arm is replaced by one curved to a parabolic form (*fig.* 2). This is mounted in the ordinary casting which supports the arm of the semaphore, and it rotates about the axis on the post, which is also the axis of the paraboloid, and in the focus of which the lamp is placed. The upper part of the lamp being red and the lower part clear (or green; *fig.* 1), the arm, when horizontal, is illuminated with the reflected red light and appears as a red band, and, when the arm is dropped, white or green as the case may be. The Koyl semaphore promises to be very useful, as it cannot be confounded with any of the numerous side-lights along the railway-track at night.

The "Block System."—The plan that has been found to afford the greatest assurance of safety, and that is now very generally adopted, is the one in which the normal position of the signal is at *danger*. When the telegraph informs the signal-man of the approach of a train, he must move his signal to the position indicating "track clear" before the train is permitted to pass the station. When the train has passed the station, the signal returns automatically to its normal position indicating danger. The great advantage of this plan of operating the signal is that accidents from the neglect of the signal-man to attend to the setting of the signal are prevented, since in case of such neglect the signal will remain at danger and bar the passage of the train.

This system, at first adopted only at junctions and important stations, has upon all important lines been extended over the entire road, the signal-stations being placed in telegraphic communication. This constitutes what is termed the "block-signal" system (*pl.* 25, *fig.* 15), and its general introduction has proved to be exceedingly serviceable in giving admirable control of the movement of trains and in avoiding accidents. By this system the entire line of railway is divided into sections of convenient lengths (say two miles, or even less), each section being commanded by signal-stations, one at each end, which are placed in telegraphic communication. The object of this disposition is to insure that only one train at a time shall be in any one block-section upon the same track.

Operation of the Block-signal System.—In operation, the signal-man who at station A has allowed a certain train to enter his block in the direction of station B will not permit a second train on the same track to pass his station until he shall have received from the signal-man at signal-station B a message informing him that the first train has arrived at station B and has passed into the next block. A second train arriving, meantime, at station A, is halted by the danger signal until the proper signal has been received from station B, when it is allowed to proceed. By this system, an accident through the entrance of several trains into the same block at a time can arise only from the wilful disobedience of the signal-man or from his misunderstanding of telegraph-signals from adjacent stations. Neglect on his part to attend to the operation of the fixed signal will have no worse result than to bring an approaching train to a standstill at the entrance to his block, since the normal position of the signal is at danger. To guard against disobedience or inattention to signals on the part of the engine-driver, the Pennsylvania Railroad has introduced at important points a system whereby, when the track is not clear between blocks, the switch is so set as to side-track the train. This precaution is taken to avoid the greater evil of a possible collision, and is assuredly calculated to make the engine-driver exceedingly careful to observe and obey his signals.

Distant Signals.—In addition to these provisions, so-called "distant signals" are occasionally employed, whose purpose is to notify trains some distance away of their approach to dangerous points. These distant signals are operated mechanically by a wire communication from the nearest signal-station.

Interlocking Switch and Signal.—For additional security at important stations, junctions, or where a number of distinct lines communicate, it becomes necessary to provide means whereby the signals and switches can be connected with each other so that both can be operated in conjunction. The highest type of such combinations is seen in the so-called "interlocking" switch and signal systems. In these the proper setting of the switches is accomplished before the operation of the safety signal is begun, and the signal is moved to danger before the movement of the switches can be commenced. By no other systems yet devised would it be possible to control the movements of the great number of arriving and departing trains at important railway centres, and their adoption at such points has become indispensable.

Other Signal Systems.—The systems of Saxby and Farmer (*pl.* 28, *fig.* 17), the Union Switch and Signal Company, Hall Signal Company, and others of lesser note, are wonderfully ingenious, and perfect in their methods of operation. The movements of arriving and departing trains, which, as at the Cannon Street Station in London, sometimes follow one another at intervals of two or three minutes during certain hours of the day, are controlled by means of suitable levers, by which the operator shifts the switches and signals. At this station a single operator, with no less than sixty-seven such levers under his charge, receives and despatches during the busiest portion of the day at the rate of thirty-six trains per hour, each of which must be separately signalled, requiring one hundred and eight operations of shifting switches and signals.

Signal-towers.—At important locations, junctions, and the like, the signal-station is usually a tower (*pl.* 25, *fig.* 15) raised considerably above the road-level, that the signal-man may be able to command an unobstructed view in all directions, and may be isolated from everything calculated to divert his attention.

Switch-signals.—Among others should be mentioned the switch-signals, whose object is to inform the engine-driver at some distance of the position of the switches. These signals are targets of various forms and with various distinguishing colors, which exhibit by their position which way the switch is set (*fig.* 13). At night colored lights are employed for the same purpose. A special form of the switch signal used largely in Austria is the Bender (*pl.* 28, *figs.* 18*a*, *b*). In this the light of the lantern is caused, by the intervention of two cone-shaped mirrors, to be reflected upon curved disks of metal, which are so disposed in relation to the mirrors as to be uniformly illuminated.

Torpedoes.—In the event of an accident or other unusual circumstance requiring the stoppage of a train, or when it is feared that the optical signals cannot be distinguished (owing to storms, fogs, etc.), it is customary to attach to the rail small capsules containing an explosive mixture of some kind (torpedoes), which are exploded by the blow of the engine-wheels passing over them.

Signal Code.—There is, in addition to the foregoing, a variety of signals in use by the engine-drivers, conductors, train-hands, flagmen, and others, which are important means of conveying intelligence. There is no uniform code of signals of this order among the railroads of the United States, but to give the reader a general idea of their character the code in use on the typical American road (the Pennsylvania) is given as a specimen. These signals, though not identically followed by other roads, are substantially those employed by them—namely:

Red signifies *danger*, and is a signal to stop.

Green signifies *caution*, and is a signal to run slowly.

White signifies *safety*, and is a signal to proceed.

Green-and-white is a signal used to stop trains at flag-stations.

Blue is a signal used by car-inspectors.

Flags and Lamps of the proper color must be used, the former by day and the latter at night or in foggy weather. Red flags or red lanterns must never be used as *caution* signals: they always signify *danger*—"stop." A lantern swung across the track, a flag, hat, or any object waved violently by any person on the track, signifies *danger*, and is a signal to stop. An exploding cap or torpedo clamped to the top of the rail is an extra danger-signal, to be used in addition to the regular signals at night, in foggy weather, and in cases of accident or emergency when other signals cannot be distinctly seen or relied upon. The explosion of one of these signals is a warning to stop the train immediately; the explosion of two of them is a warning to check the speed of the train immediately and look out for the regular danger-signal.

A Fusee is an extra caution-signal, to be lighted and thrown on the track at frequent intervals by the flagmen of passenger-trains at night whenever the train is not making schedule speed between telegraph-stations. A train finding a fusee burning upon the track must come to a full stop, and not proceed until it is burned out.

Train-signals.—As it is important to provide means whereby the conductor and other train-hands may communicate with the engine-driver, and whereby the passengers may signal in case of necessity to the engine-driver, conductor, or guard, various forms of intercommunicating signals have been introduced. These are almost exclusively mechanical; electric devices are rarely employed. On European railways there is usually carried along the outside of the train a cord so placed that it may be reached through the window, to summon the guard. In other cases an attachment is made with the cord on the inside of the compartments. The universal practice on American railways is to provide through the entire length of the train a signal- or bell-cord which communicates with a bell in the locomotive-cab. This cord is suspended overhead within easy reach of the train-hands and of the passengers. By its use, according to a prearranged code, the conductor signals for starting or stopping. A recent innovation introduced on some American roads is a signal operated by compressed air through a tube passing under the train and connecting each car with the engine-cab. This is in addition to the usual signal-cord, and is used by the conductor to signal to the engine-driver.

Conductors' Bell-signals.—To the signal-bell, placed overhead inside the engine-cab, is attached a cord which passes through to the rear platform of the train. One tap of this bell when the engine is standing is a notice to start. Two taps when the engine is standing is a notice to call in the flagman. Two taps when the engine is running is a notice to stop at once. Three taps when the engine is standing is a notice to back the train. Three taps when the engine is running is a notice to stop at the next station.

Conductors' Lamp-signals.—A lamp swung across the track is a signal to stop. A lamp raised and lowered vertically is a signal to move ahead. A lamp swung in a circle is a signal to move back.

Whistle-signals.—One short blast of the engine-whistle (thus, –) is a signal to apply the brakes. Two *long* blasts (— —) is a signal to throw off the brakes. Two *short* blasts (– –) when running is an answer to signal of conductor to stop at next station. Three *short* blasts (– – –) when standing is a signal that the engine or train will back. Three *short* blasts (– – –) when running is a signal to be given by a passenger-train when carrying signals for a following train, to call the attention of passing trains to the signals. Four *long* blasts (— — — —) is a signal to call in the flagman or signal-man. Four *short* blasts (– – – –) is the engine-man's call for signals. Two *long* followed by two *short* blasts (— — – –) when running is a signal for approaching a road-crossing at grade. Five *short* blasts (– – – – –) is a signal to the flagman to go back and protect the rear of the train. A succession of *short* blasts of the whistle is an alarm for cattle, and calls attention of trainmen to danger ahead. A blast of the whistle of five seconds' duration is a signal for approaching stations, railroad-crossings, and drawbridges.

12. SPECIAL RAILWAY SYSTEMS.

Inclined-plane Railways.—Before the day of the locomotive, inclined planes operated by cables or bands were used for raising or lowering loaded wagons upon steep inclines. When the load was to be lowered, it was sufficient that it should have enough overweight to raise the empty wagons up the slope by gravity, the speed regulation being effected partly by ballasting the ascending train (with water, for example) and partly by a suitable brake. In this case the cable or band was passed over a drum at the summit of the incline. When the load was to be lifted up the slope instead of being lowered, an endless cable or band was employed, which passed over drums located at the top and bottom of the incline. A stationary steam-engine at the summit was used to set the upper drum in rotation. The loaded wagons to be drawn up the slope were attached to the cable by various devices (hooks, pushers, etc.), and were also provided with suitable brakes, and occasionally, in addition to these, with certain automatic safety appliances. The greater number of the inclines formerly operated by stationary engines and cables are now abandoned, the construction of more powerful locomotives having made it possible to dispense with them. Several inclines in connection with steam-railways operated by cables and stationary engines are in use in France, Belgium, and Germany. In the United States similar plans on an extensive scale, in connection with city railway-lines, are in use, notably in Cincinnati (*pl.* 34, *fig.* 4), Pittsburgh, and elsewhere.

Incline with Stationary Cable.—A modification of this cable system has been proposed by an Italian engineer (Agudio), and tried successfully on a section of the Turin-Genoa railway. The stationary engine at the summit is dispensed with, and the cable, which is stationary, plays a *rôle* analogous to that of the cables in the so-called "Belgian canal-towing" system. In other words, a motor-car provided with several rotary pulleys draws itself and the train attached to it up the slope by gripping the cable. Other modifications of this plan will be mentioned in connection with passenger railways in cities (tramways).

The "Switchback" Railway.—In the anthracite coal-regions of Pennsylvania the so-called "switchback" system, used in connection with the inclined planes just described, was introduced over forty years ago, and is still largely employed. By this system the coal-cars are lowered from the summit by gravity, the steep gradient of the mountain-side being avoided by constructing a series of zigzag lines of comparatively gentle incline, along which the cars run backward and forward. The plan was first introduced to lower coal-cars into the Nesquehoning Valley, and soon came into general use in the coal-region of Pennsylvania. It offers a very simple solution of a troublesome engineering problem. It will be understood that the cars come to a full stop at the end of every piece of line composing this zigzag system, so that the danger of their getting beyond the control of the brakes is thereby avoided. This system has been introduced by American engineers with success on the Callao, Lima and Aroya (now Transandine) Railroad, in Peru, in many respects the most remarkable specimen of railway engineering in the world. Until quite recently it was also employed on the Cascade division of the Northern Pacific Railroad as a temporary expedient to cross the "Stampede Pass" while a tunnel (since completed) 9850 feet in length was being driven through the mountain.

The "Big Loop."—A notable example of the methods for overcoming the difficulties of a steep ascent by a series of curves is illustrated by the so-called "Big Loop" (*pl.* 34, *fig.* 1) on the Georgetown branch of the Union Pacific Railroad, in Colorado, between Georgetown and the mining-camp of Silver Plume. The actual linear distance up the valley in this case is one and a quarter miles and the vertical distance of the ascent is 600 feet, to overcome which would require, with a straight line, a gradient of 480 feet to the mile. To obviate this, the line of the railroad was constructed in spiral form, with the result that, while it became necessary to increase the length of the line to four miles, the gradient was thereby reduced to 150 feet to the mile.

Atmospheric Railways.—Atmospheric railways made their appearance almost simultaneously with the steam-railways. The motive-power in this system is the pressure of the atmosphere. The idea of moving carriages by means of atmospheric pressure appears to have originated at the close of the seventeenth century with Dr. Papin of Blois, in France, who was also the first to study the properties of high-pressure steam. The earliest experiments in this field were by Medhurst and Pinkus, but the credit of practically constructing and operating a railway on this principle is due to Clegg and the brothers Samuda, whose experimental atmospheric railway was put in operation at Wormwood Scrubbs, in the suburbs of London, England, in 1838. Later (1844) a short stretch of road on this principle was built between Kingstown and Dalky, in Ireland (*pl.* 36, *figs.* 1, 2). This was about two miles long. Following this came the atmospheric railways from London to Croydon, from Exeter to Plymouth, in England, and lastly (1847) from Nanterre to St. Germain, in France.

The principle of construction and mode of operation of these railways will be understood from the following: Imagine a tubular chamber, sealed air-tight, with a piston in one end fitting exactly and capable of motion to and fro. If a partial vacuum be created in advance of this piston by pumping out the air, the piston will move forward, because the entire pressure of the atmosphere is exerted on the back of the piston, to which the pressure in front, having been reduced by the pump, offers but slight resistance. Imagine, also, this piston to be connected with a car running on rails over the tube by means of an arm projecting through a slot in the tube (*fig.* 1), the entrance of air through the slot being prevented by providing the latter with a series of elastic valves. Under such circumstances the car will move forward with a force depending on the diameter of the piston and the amount of vacuum maintained in the tube. To open the valves covering the slot in the tube, so as to allow of the passage of the projecting arm, various mechanical artifices may be employed, of which one is that of a roller suitably connected to the piston and moving in advance of it. After the arm has passed, the valve is closed behind it by a similar roller attached to the car, and the tube will thus be kept air-tight, only that portion of it immediately at the projecting arm being open. The vacuum is created by means of an air-pump actuated by steam-power. Since the year 1849, however, roads of this character have been abandoned, for the reason—apart from their inconvenience—that their operation was found to be too costly. The amount of vacuum which it is necessary to maintain in a tube of the kind described will be from seven to ten pounds, and the unavoidable leakage through the slot is so considerable that the plan is found to be impracticable.

Pneumatic Railway.—In contrast with the atmospheric is the pneumatic railway, in which the car is placed, not outside, but inside, the closed tunnel-like tube, which completely surrounds it (*pl.* 37, *fig.* 2). In this system the car itself forms the piston, and, in consequence of the large extent of surface which it exposes to the atmosphere, a comparatively small difference of pressure (one-tenth of an atmosphere) is required to set it in motion. On account of the trifling pressure needed to actuate the car, it is not necessary to be so exact with the fitting of the car-body to the walls of the tube, and small leaks may be disregarded. To maintain the necessary difference of pressure on both sides, a yielding brush-like packing is found to answer the purpose satisfactorily. The system may be operated equally well by vacuum or by pressure. Hence, the car may be moved to and fro in the tube by the use of an engine at one end of the line which shall give a blast and exhaust alternately.

Pneumatic Despatch-tube.—The idea of utilizing a tube and a plenum, or exhaust, for the conveyance of lighter articles of freight, small packages, letters, etc., has been universally put in practice. Medhurst had a very clear conception of the utility of this system of transportation, but was half a century in advance of his time. London was the scene of the first practical trial of pneumatic transit. In 1859 a pneumatic despatch-tube was laid down to convey parcels and light goods from the Euston Square Station of the North-western Railway to the district post-office in Eversholt street (*pl.* 30, *fig.* 25). It proved entirely successful, and the system has since been considerably extended in London and other large cities; so that it has now come into general use not only for the transmission of mail-parcels to and from district offices, but also in telegraph bureaus and in large business establishments for the expeditious transfer of packages and communications from one department to another.

London Pneumatic Passenger Railway.—The pneumatic tube for the transmission of passengers and freight as well as for light parcels has been introduced in London between Holborn and Euston Square. The tube is of cast iron, each section being about 9 feet long, 4 feet wide, and 4 feet 6 inches high. The carriage, which runs on rails laid on longitudinal sleepers, weighs half a ton and can carry a load of one and one-half tons. Knight states that in ordinary working twenty-four trains, a gross weight of two hundred and forty tons, have been carried over this road in four hours. The pressure required does not usually exceed one half-pound to the square inch. The carriages may be sent through either by pressure or by exhaustion. A fan 22 feet in diameter is employed.

Crystal Palace Pneumatic Railway.—A pneumatic system for the conveyance of passengers has been put in operation at the Crystal Palace, Sydenham, London. The following data respecting this railway are given by Knight: The line is laid between the Sydenham entrance and the armory near Penge Gate. The tube is a simple brick tunnel 9 feet high and 8 feet wide. It is about a third of a mile long, with several sharp curves, and very little of it is level, one incline being 1 in 15. The size of the tube renders it capable of receiving an ordinary railway-carriage. The piston is provided with a fringe of bristles, which forms between it and the walls of the tunnel an elastic packing sufficiently air-tight for the purpose required. A fan 20 feet in diameter is employed to exhaust or force the air. The entire distance, six hundred yards, is traversed in fifty seconds with an atmospheric pressure of only two and a half ounces.

Beach Pneumatic Railway.—In the United States the use of the pneumatic despatch for the conveyance of letters, parcels, etc., is very general. A section of pneumatic railway intended for freight and passenger service on the plan devised by E. A. Beach of New York was laid a number of years ago under Broadway in that city, but continued in use only a short time. The Beach system embraced special devices for the delivery of letters and parcels at intermediate stations along the line. The interior of the car is shown on Plate 37 (*fig.* 2).

Mountain-railways: Fell's System.—In recent years, a number of mountain-railways, notably for the convenience of tourists, have been constructed, and to overcome the very steep gradients special modifications of the motor and of the track have been introduced. In the system devised by Fell (*pl.* 26, *figs.* 24, 25) a high central rail is laid between the two ordinary rails. Upon this central rail, pressed against it by springs, run the four horizontal driving-wheels of the locomotive. By this artifice the adhesion of the engine to the rails is increased and it is enabled to overcome the steep gradients. The amount of pressure thrown on the centre rail by the driving-wheels is under the control of the engine-driver. Besides the ordinary brake mechanism applied to the vertical wheels, a special form of safety-brake operating as a clamping device is employed together with the centre rail. This system, after a successful experimental trial on the inclined plane of the Cromford and High Peak Railway, was put in operation during the construction of the Mont Cenis tunnel, in connection with the temporary railway constructed from St. Michael over Mont Cenis to Susa. The average gradient of this road, some thirty miles in length, was 1 : 25.6, the maximum being 1 : 12. The radius of the curves was as low as 130 feet. The gauge of the track was 3 feet 8½ inches. The railway occupied 13 feet of a pre-existing roadway, whose course it followed, the unoccupied portion being left free for the common road-traffic. The locomotive had two axles spaced 7½ feet apart, and weighed, when loaded, twenty-two tons. Railways upon this system have been constructed in Brazil.

Mount Washington Railway.—What is believed to be the first mountain-railway operated by locomotive power is that constructed up the slope of Mount Washington, in the White Mountains of New Hampshire (*pl.* 34, *fig.* 3). It was built after the plans of Sylvester Marsh, and was designed to afford the great throngs of summer visitors a convenient mode of ascending to the summit, some 6000 feet above sea-level. In 1866 a short piece of experimental track was laid up the lower slope of the mountain, and an engine was built to attempt the ascent. It proved successful, and in 1869 the road was completed to the summit; in the same year it was opened for traffic, and has continued in service to the present time.

The road-bed of the Mount Washington Railway is mainly a trestle-work of timber cut from the forest of spruce that covers the lower slopes of the mountain. The rails are of the ordinary strap pattern, laid on longitudinal timbers, with a gauge of 4 feet. In the middle of the track a third longitudinal timber is securely fastened and surmounted with a heavy rack-rail, into which steel pinions engage from the engine and car. The motive-power is a locomotive engine working through countershafts and pinions into this central rack. Iron pendants from engine and car with flanges turning under the longitudinal timbers are provided to guard against the accident of the lifting of the train from the track by the wind or other cause; and by a combination of atmospheric brakes and brake-straps on the pinion-shafts the train can be stopped under all emergencies. The engine is placed behind the car in ascending and retains this position in descending. It has an upright boiler and a horizontal cylinder; its weight is about seven tons. The car is of the ordinary American pattern, but about one-half the usual size, and the seats are hung on stirrups, so that they shall retain their horizontal position under all circumstances. The length of this railway is about three miles, and the time required for ascending or descending is about one hour. The maximum grade is 1700 feet to the mile, and the average is 1300 feet to the mile. This railway was the prototype of the Vitznau Railway, Switzerland, next to be described.

Rigi Railway.—The idea of constructing a railway up Mount Rigi was conceived by the German engineer Riggenbach after an inspection of the Mount Washington Railway, above described. The Rigi road, which was built by the engineer just named, in association with Naeff and Tschokke, and was opened for traffic May 23, 1873, starts from Vitznau, a village on the banks of the Lac des Quatre-Cantons, and rises up the mountain-side to a station at Staffel-Höhe, above the hotel and bath establishment called Rigi-Kaltbad, well known to tourists. The length of the line is 5760 yards (about three and one-quarter miles), and the height of the upper terminus above the lower is 3937 feet, making the average gradient 1 in 4½ (the grades vary from 1 in 5½ to 1 in 4). The radius of all the curves is 600 feet. The superstructure is formed of cross-ties spaced, approximately, 2½ feet apart and resting on stringers, the whole being united in such a manner as to form a very substantial structure. On the cross-ties are fastened a track of the ordinary pattern (of nearly normal gauge) and a central toothed rail or rack.

The locomotive with tender weighs about twelve tons, and is furnished with an upright boiler placed at such an angle that it maintains a vertical position on the average gradient of the road. In the ordinary locomotive traction is caused by the adhesion between the driving-wheels and the rails; in the engine just described the wheels serve merely as carriers. By a simple arrangement of gearing upon the axle of the locomotive, a cog-wheel is made to engage with the rack-rail and thus to advance the train. This peculiarity constitutes the essential novelty of the system. The speed of ascent is at the rate of three and one-fifth miles per hour.

The train is composed of a single carriage and the locomotive; in front of the boiler a platform, surrounded by a suitable railing, serves for the reception of the baggage. The cars are two-storied, seats being provided on the roof. In ascending the mountain the car is pushed by the locomotive, while in descending it is retarded by the simple artifice of admitting air to the cylinders in place of steam and permitting this to escape through a small but regulable orifice, causing the piston thereby to act the part of an air-brake. For stopping the train, cog-wheels are adapted to the cars as well as to the locomotive. This provides greater security, as the car may be stopped independently of the engine.

Weltli System.—In the system devised by Weltli the locomotive is furnished with a roller mounted upon an axle at right angles with the axis of the road. Around the periphery of this roller a series of ribs are arranged spirally. These are designed to engage with corresponding parts of supplementary rails. The locomotive has the usual driving-wheels running upon smooth track-rails, and the supplementary driver is brought into service only upon those stretches of the line where the gradient is so steep as to require greater adhesion.

Primitive Elevated Railways.—Post-roads are more or less primitive constructions designed for special service. In these, posts of wood or metal are substituted for the regular road-bed. To these posts, which are driven into the ground with more or less solidity according to the nature of the traffic the road is intended to carry, and which project a certain distance above the ground-surface, is secured a heavy stringer, which serves at the same time for road-bed and ties, and to this the rails are secured. Such roads are well adapted for lumbering districts, where they are not required to be permanently located, since the entire plant may easily be removed from place to place as circumstances demand.

Wire-rope Transmission.—In situations where other means of transportation are not available, on account of local impediments, various forms of wire-rope transmission are employed with decided advantage for the transfer of materials. The oldest and most primitive of these arrangements consists of a single wire rope (or two parallel ropes) supported upon a single post-line. The carriers (buckets and the like) for the material to be transported are suspended from this line, and are carried to and fro by means of a second wire rope attached to them. In the system devised by Hodgson, which is an improvement upon that just named, the second, or traction, rope is dispensed with, and the carrying rope is set in motion by some suitable motive-power, and conveys the suspended loads along with it, discharging the contents of the carriers at one terminal and returning the empty vessels to the other to be reloaded. A number of modifications of the system of wire-rope transmission have been proposed, and to some extent adopted. On Plate 35 (*fig.* 6) is shown a system of this description in operation. It is of special service in transporting crude materials (coal, ores, etc.) short distances, down mountain-sides or across rivers and ravines, and to situations difficult of access where other means of transport would entail much loss of time and more expensive structures. In large industrial establishments, factories, mills, etc., the use of the travelling wire rope for transporting materials from one department to another is not uncommon.

Telpherage System.—A system of wire-rope transmission, known as "telpherage," in which electricity is the motive-power, has lately been devised by the English electrician Fleeming Jenkin (*fig.* 4). Professor Jenkin has proposed this system as a substitute for the overhead wire-rope system just described, which the fixed portion of the telpher line generally resembles. In the telpherage system, however, the line is immovable, and the carriages are driven by simple electrical appliances. Like the travelling wire-rope system, the telpherage system may be employed with advantage for the conveyance of minerals, ores, etc., from mines or quarries to shipping-stations at moderate distances (from one to twenty miles), and where canals or railways do not exist it affords a cheap method of inland conveyance for raw products and goods when these are of such a nature that they may be divided into parcels of one, two, or three hundredweight.

Telpher Line at Glynde.—The telpher system has been practically introduced at Glynde, in England, where a line about one mile in length was put in operation in 1885 to carry clay from the pit to the nearest railway-station. It consists of a series of posts spaced 60 feet apart and furnished with two lines of steel rods supported by cross-heads at the posts. Each of these lines carries a train, one being the "up-line" and the other the "down-line." The line is divided into electrical sections, and each section, having a length of 120 feet, is insulated from its neighbor. The line wire is supported at the posts by cast-iron saddles curved so as to facilitate the passage of the wheels over the point of support. Each alternate section is insulated from the ground, and all the insulated sections are in electrical connection with one another, as likewise are all the uninsulated sections.

The train is 120 feet long—the same length as that of a section. It consists of a series of seven buckets and a motor, which are kept evenly spaced by the interposition of distance-pieces of ash. Each bucket will transport a load of two and one-half hundredweight, and the bucket—or "skip," as it is called—weighs, with its load, three hundredweight. The weight of the motor is three hundredweight. The skips are suspended below the line, from one or from two V-shaped wheels, being supported by arms, which are curved out sideways to clear the supports at the posts.

The motor on the locomotive also hangs below the line, being supported on two broad, flat wheels and driven by two horizontal gripping-wheels.

A wire connects one pole of the motor with the leading wheel of the train, and a second wire connects the other pole with the trailing wheel; the other wheels are insulated from one another. Thus the train, wherever it stands, bridges a gap separating the insulated from the uninsulated section. The insulated sections are supplied with an electric current from a dynamo driven by a stationary engine, and the current, passing from the insulated to the uninsulated section through the motor, drives the locomotive. From this description it will readily be understood that, given sufficient power, any number of trains can be driven one after another continuously on such a line. The motors employed on the locomotives of this line were designed by Ayrton and Perry, and are reputed to develop great power for their weight, one weighing ninety-six pounds developing one and one-half horse-power, and another weighing thirty-six pounds giving nearly one-half horse-power. The details for blocking to prevent collisions, for the construction of sidings, and for loading and discharging have all been carefully worked out.

It is claimed for this most ingenious system of electrical transportation that such lines will find their application in all cases where the traffic is sufficient to pay interest on a small outlay, but is insufficient to pay interest on the cost of constructing even the cheapest form of railway. As compared with the travelling wire rope, the telpher line is claimed to be simpler and cheaper, as pulleys and other operative parts are dispensed with and no second rope is required; the cost of maintenance is less; the direction of the line can be changed as often as may be desired so as to follow a winding course, which is difficult to accomplish, even to a limited extent, with wire-rope haulage. At present there are two telpher lines in operation—one an experimental line, at the telpherage company's works at Werton, England, and the other the Glynde line, above described.

Post-line Railways.—In treating of special forms of railroads it will be necessary to make some reference to the post-line, or elevated, railroads which have lately come into prominence, more especially in the United States, as a means of solving the difficult problem of providing rapid transit in the large cities and between the business-quarters of the cities and the suburban districts. The earliest suggestions for such elevated roads were intended to provide means for the more convenient transportation of commodities of various kinds; later on they were adapted to meet the requirements of passenger traffic.

Figure 1 (*pl.* 35) represents one of the earliest of these post-roads, proposed by Palmer in England in 1821. It consisted of a beam carrying a single rail on top and supported upon a line of posts. A vertical wheel runs on this rail, and from this the load is suspended on each side. The system of Sargeant, an American inventor (1825), was substantially the same as that of Palmer. The Bryant and Hyett plan (1831) was based on substantially the same principle as those above named, but was more elaborately planned to serve for passenger as well as goods traffic. Emmon, in the United States (1837), in addition to the post-line, the single rail, and the vertical wheel riding upon it and carrying the car pannier-fashion, extended the latter down on each side of the post, and on the posts introduced side-rails, on which horizontal wheels were to run to steady the car. Figure 2 is a section of a single-rail post-line road built by General Le Roy Stone of New York over the Belmont Ravine on the grounds of the Centennial Exhibition at Philadelphia in 1876. This road, which was successfully operated during the exhibition, consisted really of three rails instead of one, the supporting portion of the post being triangular in section, with a rail at each point of the triangle. The supporting-rail was at the top, the lower rails serving as horizontal steadying-wheels for the saddle-bag car.

C. CITY AND SUBURBAN RAILWAYS (TRAMWAYS).

Horse-railways (called tramways in England, and to some extent elsewhere) preceded steam-railways in point of time, but since the introduction of the latter they are rarely used for the transport of merchandise, their employment for this service being confined principally to the case of industrial works where the question of speed is an unimportant one, and where, on account of the shortness of the distance to be traversed, it would not be profitable to employ locomotives. This mode of transportation is used to some extent, however, for the conveyance of merchandise between the freight-dépôts of the railways and certain distributing centres in cities, such as market-houses, warehouses, etc., although in the majority of cases of this kind the loaded freight-cars are simply hauled to and from these places by animal traction over the ordinary railway-tracks, which are extended to make the necessary connections.

Tramways.—Knight defines tramways as flat boards, balks, or paving-stones laid down to form a way upon which the wheels of the trams (wagons) could roll more easily. These primitive devices were succeeded by rails made of wood (1676), which are described as being supported on transverse sleepers and shaped so that the four wheels of the wagon fitted to them. Within the past twenty-five years, street-railways have been very extensively introduced for passenger travel in cities, and to provide means of transit between the suburbs and the business centres. Considered historically, the street-railway is the outgrowth of the tramroad system which was used in the English collieries two centuries ago (see p. 171).

Passenger Railways in cities were first introduced in the United States about the year 1850. Some ten years later, though only after meeting with violent opposition, they came into use in England. Since that time they have come into general use throughout Europe. The roadway is commonly placed on a level with the street, following the grade of its surface. The rails in common use for the street-railway are of the form shown on Plate 20 (*figs.* 10–15), and are fastened with spikes (more rarely with bolts) to longitudinal sleepers, which, in turn, are secured to cross-ties, to give the necessary transverse stiffness to the line. The form of rail shown in

Figure 14 (*pl.* 20) is generally adopted. It has the advantage of allowing the passage of moving wagons on its broad surface—a convenience of which the drivers of vehicles generally avail themselves; but, on the other hand, the vehicles are liable to be wrenched severely, and frequently wheels and axles are broken, when the attempt is incautiously made to turn out sharply from the track or to cross it at an acute angle. The track formed of rails of the general pattern of Figure 15 cannot be used by wagons and carriages, and consequently is not liable to cause accidents of this nature. Experiments have been made, both in America and in Europe, with a view of dispensing with the use of the wooden stringers, the rails for this purpose being laid in a specially-prepared bed of gravel or concrete. Such experiments, however, have not demonstrated any utility.

Street-railway Cars.—The cars in common use on the street-railways are four-wheeled vehicles capable of accommodating from twenty to thirty passengers. The American pattern, with the seats arranged lengthwise, is that in general use; more rarely, especially for summer traffic, the seats are arranged across the car. The car first named affords greater convenience of ingress and egress to passengers, and, as the doors may be closed in cold weather, it may conveniently be heated. The wheels of the passenger-cars (*Anglicé*, tramcars) are flanged like those in use on the steam-railways, the form of the flange varying according to the style of rail.

Modified Street-railway System.—A novel variety of the street-railway which is worthy of mention, and in which the car may leave the track and return to it at pleasure, is the so-called "perambulator" system devised by Haworth, and introduced in Salforth, near Manchester (England), and also in Geneva. Between the two flat rails for the wheels there is placed a central grooved rail of V-section, supported on stringers like the others. Connected with the front axle of the car is a small fifth wheel, to act as a guiding-wheel, which may be lowered into the grooved rail or raised out of it by means of a treadle controlled from the driver's seat. By this device the car may be united to the track or made independent of it.

Cable Traction for City Railways.—In 1873, Hallidie, an American inventor, devised a system of cable traction for street-railways which, with some modifications of detail, has been adopted, with good results, in a number of American cities. The elements of this system are an endless wire rope buried in a conduit placed in the centre of the track-rails, which conduit has a continuous longitudinal slot, which comes flush with the surface of the ground (*pl.* 37, *figs.* 6–9); a series of supporting rollers for the cable, placed inside the conduit at convenient distances apart (*fig.* 7); a stationary winding-engine, located, usually, at one of the termini of the line, by which the cable is made to travel in the conduit at a predetermined rate of speed; and a car provided with a suitable lever passing through the bottom of the car and through the slot in the conduit, and having at its lower extremity a suitable clutch, or "grip," for taking hold of the travelling cable when the car is to go forward (*fig.* 6). The rails are of the ordinary flat pattern, laid as usual. The conduit is generally oval in section, and is made of cast iron, in sections of from 12 to 15 feet in length, bolted together to form a continuous tube. This tube (laid upon a substantial foundation, sometimes cement) is placed at regular intervals in communication with the sewers, to insure suitable drainage, and provided with numerous covered manholes, to permit of inspection.

Cable Roads in American Cities.—The cable-traction system was introduced for the first time in 1873, in San Francisco, California, where the numerous and steep gradients of certain important thoroughfares interposed serious obstacles to the economical operation of the ordinary horse-railway. It was found fully to answer its intended purpose, and others of the same type were established in that city with equal success. From this beginning it has been extended, and at the present time is used in Philadelphia, Chicago, Detroit, Kansas City, and elsewhere. The difference in the topography of San Francisco and Chicago—the one being very hilly, and consequently furnishing many steep grades to be overcome, and the other being nearly on a dead level—speaks well for the practicability of the system under the most diverse conditions, as in both these cities the cable line works satisfactorily. No difficulty is experienced in operating the cable road at all seasons. The usual rate of travel is about six miles per hour, though on suburban roads this is considerably exceeded. The cable-traction system is more economical in operation than the method of animal traction which it replaces, and is free from the obvious objections to the latter on sanitary grounds. It affords one of the most practical solutions of the street-railway problem that has been devised.

Steam Motors on City Roads.—The experiment has been made at various times to substitute steam as a motive-power for surface-roads in cities, and a number of compactly-built steam-motors have been devised for this special service. Except for suburban lines, however, the use of steam has been almost entirely abandoned on surface-roads within the built-up areas of cities. Aside from the general objection to the use of locomotives in crowded streets, the plan of using steam-motors is open to the objection that it renders existing rolling-stock of the surface-roads practically useless, and involves too great an outlay of capital for the substitution of a system whose advantages at best are questionable. On suburban roads connecting with the street-railway lines steam is very generally used as the motive-power, locomotives (dummy engines) of small size and power specially built for this service being employed.

"Fireless" Locomotive.—Worthy of mention in this connection is the system introduced in 1875 on a three-mile section of the New Orleans and Carrollton Railway (in the suburbs of New Orleans), in which the locomotive is charged with steam of the requisite pressure from a supply-boiler at one of the termini. The use of a furnace and fuel is by this means dispensed with, the locomotive (which can be considerably reduced in size) being charged at the starting-point with steam enough to serve for the round trip. This form of engine was termed the fireless locomotive. The system has been introduced in France by M. Francq, who made certain

improvements in the details of locomotive construction, and was put in service in 1879 on a short line of railway between Reuil and Marly-le-Roy with complete success. The system appears to have much to recommend it to the favorable notice of engineers.

Compressed-air Motors.—Self-propelling cars actuated by compressed air have been successfully adopted for passenger railways in cities. One of the most notable examples of this kind is afforded by the Nantes tramway, a line of about three and seven-eighth miles through Nantes, from Doulon, an eastern outskirt, to Chantenoy, its western terminus. The system employed is that of Mekarski. It was introduced in 1879, and so well answered all the demands of practice that in 1882 one of the metropolitan tramway companies of London determined to adopt it on the Caledonian road, which runs from King's Cross to Holloway.

Electric Railways in Cities.—The past few years have witnessed the introduction of electricity as the motive-power for city and suburban railways, and the details of these electric systems of transmitting power have been so far improved that electric railways are rapidly coming into use upon such lines. For surface-roads in cities and for suburban roads communicating with them the electric system possesses such decided advantages, if not in economy, at least in convenience, over all others yet proposed and used, that it appears to be merely a question of a little time when it shall entirely supersede them. The first electric railway was a short experimental line built by Siemens and Halske on the grounds of the Electrical Exhibition held in Munich in 1880. It is shown on Plate 36 (*figs.* 3–5.)

The First Electric Railway for public service was built by Siemens and Halske at Berlin, and was opened in May, 1881, between Lichterfelde and the Cadettenhaus. It is one and six-tenth miles long, with a gauge of 39 inches. In this the current is sent along the insulated rails and actuates an electric motor carried beneath the car, which transmits its motion to the wheels, with which it is connected. On this road a speed of eighteen miles per hour can be attained, although the maximum speed permitted is nine miles.

Different Systems.—The success of this pioneer railway stimulated the ingenuity of inventors on both sides of the Atlantic, and the progress made in the development of this mode of transmission has been most surprising. At the present time the plans in use may be divided into (1) the overhead system, in which the current, generated at a central station, is conveyed to the motor-truck by a contact-trolley communicating with an overhead conductor carried on a line of posts (*pl.* 37, *fig.* 1); (2) the third-rail system, in which a supplementary rail conveys the current from the station, the motor attached to the car-truck taking the current from this and returning it through the ordinary rails; (3) the underground conduit, in which an insulated conductor is placed, and from which the current is caused to actuate the motor on the truck through the intervention of various forms of contact devices passing through a suitable slot provided in the conduit for that purpose; and (4) the storage-battery system, in which the railway-car carries its own supply of electric power in the form of secondary batteries (accumulators) that have been previously charged. These are placed in a recess provided for their reception in the sides of the car, and are placed electrically in connection with the motor-truck.

The storage-battery system would appear to be the ideal system. It dispenses with the necessity of a continuous conductor, the electrical generator and motive-power are all contained within the car, and there is apparently an entire absence of any possibility of danger to passengers. The Julien storage-battery system at the present time appears to be the representative one of its kind, and has lately been introduced with satisfactory results on the Fourth Avenue surface-road in New York City. The system, however, is open to the objection that the amount of weight required to be carried to furnish the necessary power is considerable, and it does not return so high a percentage of useful effect as could be wished. These deficiencies, however, bid fair to be remedied in time. The system of Sprague, employing the overhead conductor, appears to have taken the lead in popular favor in American cities, as the table opposite will exhibit. A view of the latest form of electric motor-truck employed in the Sprague system is shown in Figure 6 (*pl.* 36).

Electric Railways in Operation.—It may be stated, as a fact of general interest, that in the matter of applying electricity as the motive-power this country is far in advance of Europe, where little has been practically accomplished in this direction. Many thousands of electric motors are in regular service in all parts of the United States, and the application of the electric system to street railways in cities and towns is rapidly extending. As a matter of historic interest, there is appended a list of the railways in Europe and America which employ electricity as the propelling power. This list, so far as reliable data can be obtained, is complete up to January 1, 1889:

ELECTRIC RAILWAYS IN EUROPE.

Town.	Line.	Length.	System.
Amsterdam	Cortverloren Park	½ mile. . .	Siemens.
Berlin	Lichterfelde-Cadettenhaus	1.6 miles . .	Siemens.
Blackpool	Blackpool Tramway	2 " . .	Holroyd Smith.
Brighton	Brighton Beach	1 mile . . .	Volk.
Brighton	Brighton and Shoreham Railway . . .	4 miles . .	Accumulators.
Brussels	Tramways	. . . . . .	Accumulators (Julien).
Charlottenberg . .	Spandauer Rock	. . . . . .	Siemens.
Cologne	Tramways	. . . . . .	Accumulators (Huber).
Frankfort-on-Main .	Frankfort-Offenbach Railway	4.1 miles . .	Siemens.
Glynde	Glynde Clay Pits	1 mile . . .	Telpherage.
Hamburg	Tramways	. . . . . .	Accumulators (Huber).
Hohenzollern . . .	Hohenzollern Colliery (Upper Silesia) .	½ mile . .	Siemens.
London	Stratford and Manor Park	4 miles . .	Accumulators.
Newry	Bessbrook and Newry	3¼ " . .	Hopkinson.
Portrush	Portrush and Bushmills	6 " . .	Siemens.
Ryde (I. W.) . . .	Ryde Pier	¾ mile . .	Siemens.
Vienna	Moedling-Hinterbrull	2.8 miles . .	Siemens.
Zankerode	Zankerode Mines (Saxony)	½ mile . .	Siemens.

Electric Railways in the United States and Canada.

Town.	Line.	Length.	System.
Akron, Ohio . . .	Akron Electric Railway Co.	6½ miles .	Sprague.
Allegheny, Pa. . .	Observatory Hill Passenger Railway Co.	3.7 " . .	Bentley-Knight.
Ansonia, Conn. . .	Derby Horse-Railway Co.	4 " . .	Van Depoele.
Appleton, Wis. . .	Appleton Electric Street Railway Co. .	5.5 " . .	Van Depoele.
Asbury Park, N. J. .	Seashore Electric Railway Co.	4 " . .	Daft.
Baltimore, Md. . .	Baltimore Union Passenger Railway Co.	2 " . .	Daft.
Binghamton, N. Y. .	Washington Street Asylum and Park Railroad	4.5 " . .	Van Depoele.
Boston, Mass. . . .	West End Street Railway Co., Brookline Branch	12 " . .	Sprague.
Brockton, Mass. . .	East Side Street Railway Co.	4½ " . .	Sprague.
Carbondale, Pa. . .	Carbondale and Jermyn Street Railway.	5 " . .	Sprague.
Cincinnati, Ohio . .	Mount Adams and Eden Park Inclined Railway Co.	1 mile.	Daft.
Cleveland, Ohio . .	East Cleveland Railroad Co.	23½ miles .	Sprague.
Columbus, Ohio . .	Columbus Consolidated Street Railway Co.	2 " . .	Short.
Crescent Beach, Mass	Lynn and Boston Street Railway Co. .	1 mile . . .	Thomson-Houston.
Davenport, Iowa .	Davenport Central Street Railway Co. .	3½ miles .	Sprague.
Dayton, Ohio . . .	White Line Street Railroad Co. . . .	8.5 " . .	Van Depoele.
Detroit, Mich. . . .	Detroit Electric Railway Co.	4 " . .	Van Depoele.
Detroit, Mich. . . .	Highland Park Railway Co.	3.5 " . .	Fisher.
Easton, Pa.	Lafayette Traction Co.	1 mile . . .	Daft.
Fort Gratiot, Mich. .	Gratiot Electric Railway	1.75 miles .	Van Depoele.
Harrisburg, Pa. . .	East Harrisburg Passenger Railway Co.	4.5 " . .	Sprague.
Hartford, Conn. . .	Hartford and Weathersfield Horse Railroad Co.	12 " . .	Sprague.
Ithaca, N. Y. . . .	Ithaca Street Railway Co.	1 mile . . .	Daft.
Jamaica, N. Y. . .	Jamaica and Brooklyn Railroad . . .	9 miles . .	Van Depoele.
Lafayette, Ind. . .	Lafayette Street Railway Co.	2.25 " . .	Sprague.
Lima, Ohio	The Lima Street Railway Motor and Power Co.	6 " . .	Van Depoele.
Los Angeles, Cal. .	Los Angeles Electric Railway Co. . .	5 " . .	Daft.
Lynn, Mass. . . .	Lynn and Boston Street Railway Co. .	2¼ " . .	Thomson-Houston.
Mansfield, Ohio . .	Mansfield Electric Street Railway Co. .	4.5 " . .	Daft.
Meriden, Conn. . .	New Horse Railroad	5 " . .	Daft.
Meriden, Conn. . .	Meriden Horse Railroad Co.	5 " . .	Daft.
New York, N. Y. .	New York and Harlem (Fourth Avenue) Railroad Co.	18½ " . .	Julien.
Omaha, Neb. . . .	Omaha and Council Bluffs Railway and Bridge Co.	9 " . .	Thomson-Houston.
Pittsburg, Pa. . . .	Pittsburg, Knoxville and St. Clair Street Railway	2¼ " . .	Daft.
Port Huron, Mich. .	Port Huron Electric Railway	4 " . .	Van Depoele.
Reading, Pa. . . .	Reading and Black Bear Railway . .	1½ " . .	Sprague.
Revere, Mass. . . .	Revere Beach Railway Co.	1 mile . . .	Thomson-Houston.
Richmond, Va. . .	The Richmond Union Passenger Railway Co.	13 miles .	Sprague.
Salem, Mass. . . .	Naumkeag Street Railway Co.	1¾ " . .	Sprague.
San Diego, Cal. . .	San Diego Street Railway Co.	9 " . .	Henry.
San José, Cal. . .	San José and Santa Clara Railroad Co.	10 " . .	Fisher.
St. Catherine's, Ont.	St. Catherine's, Merritton and Thorold Street Railway Co.	7 " . .	Van Depoele.
St. Joseph, Mo. . .	St. Joseph Union Passenger Railway Co.	9¾ " . .	Sprague.
Scranton, Pa. . . .	Scranton Suburban Railway Co. . . .	4.5 " . .	Thomson-Houston.
Scranton, Pa. . . .	Nayang Cross-Town Railway	3 " . .	Thomson-Houston.
Scranton, Pa. . . .	Scranton Passenger Railway	2 " . .	Thomson-Houston.
Syracuse, N. Y. . .	Third Ward Railway Co.	4 " . .	Thomson-Houston.
Washington, D. C. .	Eckington and Soldiers' Home Electric Railway Co.	2.7 " . .	Thomson-Houston.
Wheeling, Va. . .	Wheeling Railway Co.	10 " . .	Van Depoele.
Wichita, Kans. . .	Riverside and Suburban Railway Co. .	7 " . .	Thomson-Houston.
Wilkesbarre, Pa. . .	Wilkesbarre and Suburban Street Railway Co.	3.6 " . .	Sprague.
Wilmington, Del. .	Wilmington City Railway Co.	6½ " . .	Sprague.
Windsor, Ont. . . .	Windsor Electric Street Railway Co. .	1.5 " . .	Van Depoele.

The foregoing includes only the electric railways that are actually in operation. The major portion of those in the United States has been constructed within the past two years. The number of such roads now in course of construction or projected in various cities and towns in the United States will greatly exceed those already open for traffic, from which a fair idea may be had of the rapid growth of the innovation on this side of the Atlantic.

Gravity-railway.—An ingenious gravity-railway adapted for use in cities is the system devised by an American inventor (Thompson) and shown on Plate 36 (*fig.* 7). In this the locomotive is dispensed with. The track is undulating, the inclines being so disposed with relation to the stations that the car, when started from one station, shall be carried by gravity and at a good rate of speed to the next station. As the car approaches the station a gripping mechanism operating automatically engages with a moving cable (actuated by a fixed engine at the stations), by which it is drawn up over the incline, and also, when it is desired to start from the station, over the incline beyond, when it proceeds on its way to the next station by gravity, as before. The plan is an ingenious modification of the so-called "coasting railways" in common use at seaside resorts and the like. Figure 8 exhibits one of these coasting-roads erected at Boulogne-sur-Mer.

Elevated Roads in Cities.—The city of Berlin possesses an elevated railway about seven and one-half miles in length. The structure is in the form of an elevated masonry arcade. In Philadelphia the central station of the Pennsylvania Railroad is situated in the heart of the city, which the road enters and traverses on an elevated masonry structure, 108 feet wide and with nine tracks, extending from the Schuylkill River to Broad street. In New York City the Fourth Avenue improvement of the Harlem Railroad (*pl.* 37, *fig.* 4), extending from Forty-second street to One Hundred and Thirty-third street—a distance of four and a half miles—provides for four tracks, to accommodate express and way traffic. Of the entire distance, one section of 6937½ feet is open cut, one of 4562½ feet is viaduct, and the remainder (10,662 feet) is tunnel or covered way. New York City is provided with the most extensive system of elevated railways in the world, traversing nearly the entire length of Manhattan Island; and the neighboring city of Brooklyn has also elevated railways. These structures are supported upon iron columns, permitting unimpeded traffic on the surface beneath them. Plate 35 (*fig.* 5) is a view of a portion of the Metropolitan Elevated Railway, in New York.

The Meigs Elevated Railway.—The system of Meigs (*pl.* 35, *fig.* 3), of which an experimental section is in operation in Boston, Massachusetts, is a great advance upon the comparatively crude devices described on page 237. It is a single-post line designed for steam-traffic as a rapid-transit road in that city. The plan has a number of original and meritorious features. It differs from previous lines of its class in that it is a truck system, like the ordinary railway, and is capable of turning curves readily and of being operated at high speed with as much assurance of safety as upon the ordinary railway. It has four rails instead of one, two, or three, as in those previously described, and the supporting wheels for the load are the lowest, thus insuring the greatest stability. The locomotive and cars are of cylindrical form, with rounded ends, and have other features of novelty. To demonstrate its practicability as a means of providing rapid transit, this system has been subjected to the most severe tests by a commission of engineers appointed by the city authorities of Boston, and has passed them very successfully.

Elevated and Underground Railways Compared.—The question of the relative merits of the elevated and underground systems as means of providing for rapid transit in large cities is at present attracting an unusual share of attention. A careful study of the subject will lead to the conclusion that whenever a city has so greatly extended its area as to require for its future growth better facilities than those provided by the usual surface-roads the underground railway affords the rational and ultimate solution of the problem.

The Elevated Railway.—An eminent American engineer, Professor Haupt, who has made the question of rapid transit in cities the subject of special study, makes the following comparison: The structure of the elevated railway must be in the air, and at a sufficient height to afford clearance for surface-travel and to provide for the passage of extraordinary objects; it must be between the heights of the second and third stories of the buildings alongside its route; its supports must extend into the streets, which they must obstruct to some extent. The operation of the road will be noisy—an objection that becomes very serious in summer, when doors and windows must be left open to secure ventilation. It will obstruct the light in the buildings and streets below its grade; it will afford no relief to the present surface-travel, so far as concerns the number of the vehicles and cars; and the structures could not, without extraordinary cost, be made attractive in appearance.

The Underground Railway.—The disadvantages of the underground railway are that it will require special provision for light, ventilation, and drainage, and that, to accommodate the rolling-stock of the road, it will have to be placed at least 20 feet below the street-surface, thus debarring its patrons from seeing anything of the city from the train. On the other hand, it possesses the following distinct advantages, which are believed to be more than sufficient to counterbalance the disadvantages above enumerated: It is less noisy and would make less dirt than the elevated road, and would interpose no obstruction to light or to traffic. It could be made to furnish a means of relieving the surface of much of its travel, would facilitate the handling of freight, would be more permanent and cost less to maintain, and would also confer upon the city the incidental benefits arising from having better pavements, requiring less expense to clean and maintain, and avoiding the necessity of continually breaking into them to lay or remove pipes, wires, and conduits, which has grown to be a serious evil.

It would give better drainage and provide the subways for all the city service along its route, which no elevated road can do. It would have a speed sixty-six per cent. greater than that of the elevated road, and hence render about three times as much area available for habitation within the same time-limits. It would have much greater capacity, both because of its increased velocity and by having four tracks instead of two; and, finally, it could be made to pay an indirect revenue of great value to the city.

Arcade Underground Railway.—A proposition which has the approval of the municipal authorities of New York City is the so-called "arcade" railway under Broadway (*pl.* 37, *fig.* 5). It contemplates the construction of what would practically be a second Broadway beneath the existing one. It is proposed to excavate this subway street with sidewalks at a general level of 12 feet beneath the street-surface, and between these sidewalks to construct a central roadway about 3 feet lower, to accommodate four railway-tracks, the two in the centre for fast trains, and the other two for slower trains for local traffic. The upper street is to be supported on columns and girders, with arches between. There are to be ample provisions for lighting and ventilation, and for the convenient disposition of sewers, of gas- and other mains. This plan—which, it is believed, will presently be carried into effect—would greatly lessen the overcrowding from which Broadway now suffers, and, besides, would afford the means of securing the rapid transportation of passengers and merchandise.

The experience of New York, where the elevated system has reached the limit of its usefulness, would seem to prove that some plan of underground railway must soon be adopted adequately to meet the necessity for increased facilities which the surface and elevated roads are not able to afford. Figure 3 (*pl.* 37) exhibits another scheme of underground railway which has been proposed for the relief of the passenger traffic of the American metropolis.

Rapid Transit in Cities.—The question of providing means of rapid transportation over its entire area is properly regarded as the most important single question with which each large city has to deal. A period is reached in the extension of the built-up area of every city when the ordinary surface-roads become inadequate to meet its necessities, and unless facilities are provided for more rapid transit its growth is checked; and, conversely, those cities (for example, London and New York) in which the provision for rapid transit has been promptly made as the necessity therefor became manifest have rapidly gained in population.

III. BRIDGES.

Classification.—The term Bridge is applied to certain forms of construction the object of which is to connect two points separated from each other by water, a roadway, or a ravine in such a manner that a free or open space shall be left beneath the new avenue of communication. According to the kind of traffic for which the structure is destined, road-bridges, railway-bridges, and viaducts may be distinguished. The open space under the bridge-structure may serve, according to circumstances, for the passage of foot- or roadways, or of watercourses, small or great, or of a railway; or, as in the case of viaducts, its object may be principally the saving of material. Where the two lines of communication are not at right angles to each other, the bridge which crosses one of them must be placed obliquely to the face of its abutments, and is termed an askew bridge; when the intersecting ways of communication are at right angles, the bridge is a right bridge.

Bridges may be either fixed or movable in certain parts of their structure. The latter constitute the so-called "drawbridges," designed originally as the means of communication across the moat surrounding the castles and strongholds of the mediæval period (*pl.* 40, *fig.* 4), and later to provide an open channel for navigation where bridges were built across navigable streams at so low an elevation as to interfere with the free passage of vessels beneath them. According to the mode of operating these movable parts, several modifications—such as lift, swing, rolling, and pivot bridges—may be distinguished. In this category, likewise, may be placed the pontoon-bridges, and flying-bridges or ferries.

Every bridge consists of four essential parts: (1) the roadway; (2) the supporting structure (girders, trusses, arches, chains, cables, etc.); (3) the bridge-supports (piers, abutments); and (4) the foundations.

Bridges may be classified according to the material of which they are built or according to the form of their superstructure. The first classification may be divided into wooden, stone, iron (or steel), and combination bridges, the latter being composite structures of wood and iron. In the system of construction of the superstructure, bridges may be generally classified as girder bridges (*pl.* 39, *figs.* 1, 2, 3, 6; *pl.* 43, *figs.* 1, 3, 8, 10–13, 17), in which the stress due to the load is transmitted to the supporting points as vertical pressure only; framed-girder or truss bridges (*pl.* 39, *figs.* 4*b*, 5, to which class the arch bridges of iron, *pl.* 43, *fig.* 20, as well as stone belong), in which the stress due to the load is transmitted to the supporting points also as a horizontal thrust; and suspension bridges (*pl.* 41, *figs.* 1–3), in which the supporting structure must sustain, in addition to the vertical pressure due to the load, an inward pull tending to drag the chains or wire cables from their anchorages; or, to put the case somewhat differently, in girder bridges the material of the girders, as it yields beneath the stress due to the load, suffers compression in one part and extension in another; in arch bridges the material of the arch suffers compression; and in suspension bridges the material of the structure carrying the load (chains, cables) suffers extension. Combinations of the foregoing systems are not infrequent.

The superstructure may be formed of a single span, in which case two points of support only will be needed, and these may consist of the two banks of the stream, or of masonry (*pl.* 39, *fig.* 1), or of piles (*fig.* 6); or it may be formed of a number of spans, in which case the intermediate supports are of wooden (*figs.* 2, 3, 6) or iron trestle-work, or of stone (*pl.* 43, *figs.* 8, 20) or iron piers or columns. The latter are either hollow cast-iron columns of one or more tubes sunk into the foundation and bound together, or of wrought- or cast-iron pillars or columns, usually formed each of a number of columns of small diameter firmly united with one another by bracing and supported upon low stone piers.

1. WOODEN BRIDGES.

Classification.—Considered in respect of their construction, wooden bridges may be classified as: (1) Plain girder bridges (*pl.* 39, *figs.* 1–3), in which the roadway of planks lies crosswise upon a number of girders placed parallel to one another. (2) Dovetailed and dowelled girder bridges, in which the girders are formed of a number of pieces placed one above the other and united by screw-bolts and dovetailed joints, or of cut timbers separated by dowels of hard wood and firmly united by means of screw-bolts. (3) Strut bridges (*figs.* 5, 10), in which the girders are stiffened and strengthened by struts placed below them and consisting of two stanchions and a straining-beam stiffened against the bridge supports. (4) Truss-frame bridges (*fig.* 4), or, properly, bridges with struts placed above the roadway, in which the roadway is suspended from the truss-frame by the vertical suspension-rods. The thrust of the oblique pieces, or braces, is taken by the girders into which they are mortised, so that the supporting points receive it as vertical pressure. In its simplest form the truss-frame has no straining-beam, but consists merely of the two oblique pieces or braces, united to a king-post at the centre of the girder from which the latter is suspended. (5) Lattice bridges, which are preferred for spans of considerable length, are truss bridges which differ materially in the arrangement and functions of their members. Town's lattice truss (*pl.* 39, *figs.* 8, 9; *pl.* 42, *fig.* 3) is formed of timbers crossing one another at right angles and united at the point of intersection by wooden tree-nails and having horizontal string-pieces at top and bottom, from which the floor and roof of the structure may be supported. This form of structure was at one time popular in the United States, where wooden truss bridges are largely used, but has been abandoned in favor of improved forms. In the Howe truss (*pl.* 39, *figs.* 6, 7; *pl.* 42, *fig.* 1) vertical suspension-rods are introduced, and the main as well as the counter braces bear against cast-iron angle-plates and sockets extending through the chord-pieces. By reason of the considerable depth of these girder constructions, the wooden lattice bridges are notable for their stiffness. (6) Arch bridges, whose arched main girders consist of various modifications of timber structures of arched form, according to the width of span. In the United States lattice-work arches are in vogue, and according as the roadway is carried under or over the arches they are distinguished as truss arch and strut arch. Combinations of the arch with the lattice-beam are not infrequent.

The Roadway proper in the case of wooden railway-bridges (*pl.* 39, *figs.* 6, 7) is formed of cross-ties laid at right angles to the axis of the bridge and extending from one side-girder to the other. The rails are laid either directly upon these cross-ties or, as in the illustrations, upon longitudinal sleepers placed upon the latter. Upon road bridges (*figs.* 8, 9) it is customary to lay a heavy flooring of planks upon the cross-ties, and upon this to place a lighter flooring—wood-pavement, asphalt, etc.—for the road-surface. To give the bridge-structure sufficient transverse strength to enable it to withstand the force of the wind, it is necessary to provide it with special cross-braces and wind-stanchions.

Piers and Trestles.—Examples of wooden-pile piers and trestles are shown in Figures 1, 2, 6, and 7. The construction of these supports will vary according to their height and as to whether they stand upon the land or in the water. Where the height of the structure is moderate, the first form is employed; where the height is considerable, trestle-work is used, formed, generally, of four-sided or polygonal pyramids supported upon low stone piers. To protect from damage by ice, wooden guards are often built around the piers, though a better plan is to construct special ice-breakers in front of the piers.

Wooden bridges are regarded to-day as temporary expedients, to be replaced sooner or later by structures of stone or of iron. In America, however, where timber is abundant and cheap, wooden bridges are numerous, and the art of building them has been developed to a high state of perfection.

Early Wooden Bridges: Truss Bridges.—Among the earliest examples of scientific bridge-building as applied to wooden structures was the famous bridge over the Rhine at Schaffhausen (*pl.* 38, *fig.* 4). This was one of the most celebrated wooden bridges ever built. It was planned and constructed in 1757 by a common carpenter, Ulric Grubenmann, and was burned by the French in 1799. A bridge over the Limmat near the Abbey of Wettingen, in Switzerland, was built by the brothers Grubenmann, and was also destroyed by the French in 1799. This bridge had a clear span of 390 feet—the greatest span ever executed with timber. Among the earliest and best examples of wooden bridges in America was the arch-truss erected over the Schuylkill at Fairmount, Philadelphia, in 1812 by Louis Wernwag (*pl.* 42, *fig.* 14; *pl.* 44, *fig.* 1). This bridge had a clear span of 340¼ feet. In 1838 it was burned, and its place was supplied by a single-span wire bridge (p. 269). Thomas Burr, who patented several forms of wooden-arch truss bridge, erected a number of such structures, nearly all of which exhibited remarkable durability. A peculiarity of many of these was that they were covered or enclosed, which gave them a somewhat singular appearance. A notable structure of this kind was the Columbia Bridge across the Schuylkill at Philadelphia, built in 1834 for the use of the Columbia Railroad, a State work, and subsequently sold to the Reading Railroad Company. This bridge, after having withstood more than fifty years of continuous service, has been replaced by an iron structure.

Wooden Trestle Bridges: Cæsar's Bridge.—Among the famous historic wooden bridges is the one built by Julius Cæsar over the Rhine about 55 B. C., of which he has left a description in his *Commentaries*. This account does not appear to be precise enough to permit of the reconstruction of the work without some doubt as to minor details. It is known, however, that it was a trestle bridge founded on piles driven into the bed of the river. These were joined by a beam on which joists were laid in the axis of the bridge. On these joists were laid hurdles, which supported the road-bed. Inclined beams protected the piers on the up-stream side, and each pier was stayed below by a group of piles. A reconstruction from the description left of it is shown in Figure 1 (*pl.* 38).

American Trestle Bridges.—There are several remarkable wooden trestle bridges in America. One of these, over the Potomac Creek, in Virginia, was built in 1862, in nine days, by the Federal soldiers, during the civil war, under the direction of General Haupt, chief of the Bureau of Construction and Transportation of United States Military Railroads. This structure, built of round sticks of timber cut from the adjoining woods, is 400 feet long by 80 feet high. It is in four stories, three of trestles and one of crib-work, and is still in service, carrying a heavy railway traffic. Worthy of notice, historically, is the great wooden trestle bridge known as the Portage Bridge (*fig.* 8). It was built to carry the traffic of the Erie Railway over the great gorge of the Genesee River, and was 1600 feet long and 234 feet high. Constructed in 1852, it was destroyed by fire twenty-three years later, and was at once replaced by an iron-trestle bridge. (See p. 264.)

Mexican Primitive Bridge.—Among primitive structures, the bridge shown in Figure 2 is worthy of notice as exhibiting considerable originality and ingenuity. It is described by J. Foster Flagg in the *Transactions of the American Society of Civil Engineers*, where it is credited as the production of a Mexican peon. It was built over the river Armeria, in the State of Colima. As will be perceived, it is a combination of the suspension and cantilever principles. This structure was put together without nails or metal of any kind, the suspension cable being made of twisted vines and all joints of lighter vines. The piers were made of poles driven into the river-bed in the form of a square and tied together with other poles, the interstices being filled in with stones. The stringers of the main span, in two pieces, were tied together at the centre, and the spliced stick was supported near the joint by the suspension cable. The towers were formed of natural forked sticks, which supported both the cable and the corbels, and which aided in shortening the main and lateral spans. Finally, the long stringers were again supported midway between the ends of the corbels and the central-cable attachment by cantilevers of crude construction, which were loaded with stone near their shore-ends, to balance the weight of the central span. The length of this span was about 70 feet, and that of the entire structure about 175 feet. Mr. Flagg reports that this primitive structure was strong and rigid enough to pass mounted men and loaded animals.

2. STONE BRIDGES.

Ancient Bridges: Egyptian.—The first stone bridges were doubtless stone slabs spanning small spaces. In Egypt the annual overflow of the Nile was a hindrance to bridge-construction, and no relics of ancient bridges there exist. That the Egyptians were acquainted with the arch, however, is demonstrated by the finding of an arched ceiling in the sarcophagus-chamber of one of the pyramids.

Greek and Roman Bridges.—The Greeks were familiar with the construction of the arch from the age of Perikles, but no arch bridges of that period have survived to the present time. Of arch bridges built by the Romans, about twenty remain, which have been in part restored in later times. One of the most celebrated of these is the superb structure spanning the Tagus at Alcántara. It was built about A. D. 100, in honor of the emperor Trajan. It is of granite, and consisted originally of six arches of various spans. It had a total length of 670 feet and a height of 210 feet. It has several times been partially destroyed and restored. At present a single arch only remains. The bridges of Fabricius (now Quattro-Capi) and Cestius Gallus (now Ponte-Ferrato) are old Roman structures with semicircular arches. The mastery which the Romans had acquired in this form of construction is shown by the numerous remains of their splendid aqueducts. The great sewer (Cloaca Maxima) built by one of the Tarquins five hundred years B. C., and performing its functions to-day in modern Rome after nearly twenty-five centuries of service, affords an instructive example of the substantial character of the work of these ancient masons.

Chinese Bridges.—The Chinese have long been familiar with the art of bridge-building; their bridges, like those among the Persians, are remarkable for their extreme length. In China there are arch bridges of great magnitude and of unknown but high antiquity (*pl.* 40, *fig.* 5). In his "Treatise on Bridge Architecture" (1811), Thomas Pope makes mention of a stone bridge in China, called the "flying bridge," built from one mountain to another. This is said to consist of a single semicircular arch of 600 feet span, 750 feet high.

Mediæval Bridges: Croyland Bridge.—Figure 3 exhibits the unique triangular bridge at Croyland, England, which stands at the confluence of three streams. It is formed of three pointed arches, the abutments of which are placed at the angles of an equilateral triangle. These arches meet in a common centre. This structure has three roadways. The present bridge—of which an illustration is given—is believed to have been erected about the beginning of the fourteenth century; but it has been proved from certain documents that a similar triangular bridge existed on the same site as early as the year 943.

Saintes Bridge.—Figure 4 (*pl.* 40) is an ideal representation of a famous mediæval bridge at Saintes, in France. The picture is intended to give the characteristics of this structure as it may have appeared toward the close of the fourteenth century. This restoration is due to M. Viollet-le-Duc, in whose *Dictionnaire raisonné de l'Architecture* it appears. The great tower, the crenellated parapets, and the wooden shore-ends between the first gate and the Roman arch on one side, and the tower and the town gates, which could readily be removed, on the other side were all provisions for defence.

The Bridge at St. Chamas, in France, described by Cresy in his *Encyclopædia of Civil Engineering*, is a typical specimen of a bridge built by the Romans. It affords an example of their disposition to adorn such structures with triumphal arches. This bridge, which is pictured in Figure 2, is a small single-arch span of 42 feet.

Old London Bridge.—The first stone bridge over the Thames is believed to have been built toward the close of the twelfth century. It was covered with wooden buildings, which were frequently destroyed by fire. The main portion of the bridge, however, appears to have remained intact until the beginning of this century. A roadway was left between the houses. The waterway was 336¾ feet, and two-thirds of the stream was occupied by the piers. Figure 6 is a view of this historic structure as it appeared in the year 1700.

Classification.—Stone bridges are arched structures formed of a single span when the width to be spanned is small (*pl.* 39, *figs.* 12, 13), or of a number of vaulted arches springing from piers of masonry (*pl.* 40, *fig.* 7) when the width is considerable. The roadway is supported on the arches. According to the form of curvature exhibited by the arch, several varieties may be distinguished—for example, the semicircular arch (*pl.* 39, *fig.* 12), forming a half circle from its springing lines; the low-circular or segmental arch (*fig.* 13), in which the centre of curvature lies below the line of the springings; the stilted arch, in which the centre of curvature lies above the springing lines; the low, flattened, or elliptical arch (*pl.* 40, *fig.* 7; *pl.* 41, *figs.* 6, 7); and the pointed or Gothic arch (*fig.* 13).

Arch-construction.—The form of the arch has a certain static relation to the manner of distribution of the load it sustains. The feet of the arch rest upon substantial masonry supports or abutments. The space behind the arch along the flanks is filled in with masonry (*pl.* 39, *fig.* 12) or with earth, or partly with masonry and partly with earth, to give the necessary stiffness to the structure. In arches of large size a series of parallel walls of masonry, called spandrel-walls, are built astride the arch; these are sometimes strengthened laterally by vertical cross-wall connections. The spaces left are then covered with flat stones or small arches carried from wall to wall, which thus serve as the support for the material of the roadway. Figure 1 (*pl.* 40) exhibits a half elevation and a section of the details of arch construction. To prevent injury to the arches by the penetration of moisture, the entire backs of important structures should be covered with a layer of cement-mortar, and the same material should be used liberally in the masonry above them. Special provision for drainage by means of suitable channels left for the purpose is advantageous in protecting the structure from deterioration caused by rain-soakage. The depth of the arch stones (voussoirs) either may be left uniform, or the arch stones may be made to increase in depth uniformly from the centre- or key-stone to the springers forming the two feet of the arch, the increase corresponding to the increasing pressure upon the members from the crown to the feet. This practice is not necessary in arches of small span. With arches made of hewn stone, particular attention should be given to the shaping of each member. Where broken stone or bricks are used for the arch, the selection of a proper cement becomes important; this should be quick-setting and have good binding qualities.

Centres.—For supporting the arch while it is building, temporary wooden structures—called "centres"—are used. For arches of moderate span and weight, a centre of the general form of construction shown on Plate 39 (*fig.* 12) is employed, in which a number of wooden frames or trusses placed at suitable distances apart are covered with a flooring of planks laid on edge and trimmed so as to conform to the curvature of the arch on which the arch-stones are laid. These frames are supported at their ends upon posts whose tops are united by cap-pieces and whose feet rest on string-pieces, the entire series being firmly secured together by diagonal braces. The string-pieces, in turn, according to the nature of the ground, may rest on wooden blocks, which may be adjusted to conform to any irregularity of the surface; where the earth is not sufficiently firm for this, or where the arch is very heavy, they should be supported on blocks of brickwork, or, as is frequently the case, upon projecting offsets provided for the purpose in the piers or abutments. If the arch is to be erected over water, centre supports of crib-work or piling may be necessary. In this form of centre it will be observed that the space beneath the framework is left free from obstruction, and there will be no interference to free communication while the work is progressing.

This form of centre, however, is adapted only for arches of moderate size (50 to 60 feet span). Beyond this it will be found necessary, in order to secure the requisite support during construction, to use two or three rows of posts, or to modify the construction as shown in Figure 13, in which, in addition to the braced posts at the ends, the weight of the arch is supported upon three intermediate braced posts resting in turn upon piles. In the case of the Grosvenor Bridge, at Chester, England, across the river Dee, the centre was supported by four sets of vertical and inclined posts, each set spreading out like a fan from the top of a temporary pier of masonry on which it rested. The span of this arch is 200 feet.

Lowering Centres.—When the arch is finished, the centre, having served its purpose, is removed. In the case of arches of small size, the centres are constructed with pairs of wedge-shaped blocks of hard wood, which are inserted between the cap-piece of the supporting posts and the chord of the framework. By driving out these tapering blocks the centre is gradually lowered, and the arch is left to support itself. The centre may then be taken apart and removed. As there will always be some settling of the arch more or less, according to its size and weight and the materials of which it is built, the centres are usually made a trifle higher than the finished arch is intended to be when it shall have taken its permanent set. Furthermore, as the sudden removal of the support from a heavy structure like an arch of considerable size might cause a distortion of its shape by displacement, and even endanger its stability, it is important that the centres be lowered very slowly. For arches built of brick this precaution should on no account be neglected, since this building material possesses much less strength to resist a crushing stress than granite, sandstone, or limestone. On account of the danger to be feared from this cause, screws may be substituted for the wedges for lowering the centres.

An ingenious artifice for removing centres—which is not only very simple, but is also in every way satisfactory for the purpose—consists in the use of sand-boxes. In this plan the posts or standards supporting the frames rest in short cylindrical boxes filled with sand. When it is desired to strike the centre, wooden plugs near the bottom of these boxes are withdrawn, and a small quantity of the sand is allowed to flow out; the plugs are then replaced, and this operation may be repeated frequently until the arch stands free. This method is greatly to be preferred for large arches, since it avoids violent jarring of the structure by the knocking out of wedges and affords a means of lowering the centre with great steadiness and regularity. This plan was adopted in the construction of the arch of the Pont d'Alma, in Paris (1856), referred to below. Trautwine speaks of it as being well worthy of adoption for all spans exceeding 60 feet. It may be of interest to state, also on the same authority, that in the case of railroad-cuttings crossed by bridges "the earth under the arch has been made to serve as a centre by dressing its surface to the proper curve and then embedding in it curved timbers a few feet apart and extending them from abutment to abutment for supporting the close plank lagging."

Scaffoldings.—In addition to the centres just described, in important works of this kind a temporary scaffolding of convenient height is erected along the face and transverse diameter of the intended structure, on which cranes or travellers provided with a windlass (*pl.* 39, *figs.* 10, 11) are moved to and fro upon overhead rails. These labor-saving devices are employed for raising and transporting the blocks of masonry and other building materials needed from the ground-surface to the points where they are required as the work progresses.

Semicircular Arches.—The largest masonry semicircular arch in the world is that over Cabin John Creek, on the Washington Aqueduct, built by General Meigs, U. S. A. This arch has a span of 220 feet and a rise of 57¼ feet; the crown of the arch is 101 feet above the water. The arch-stones have a depth of 4 feet 2 inches at the crown and of 6 feet 2 inches at the springers. The arch of the Grosvenor Bridge, over the Dee, at Chester, is the largest masonry arch in England. This is also semicircular, with a span of 200 feet and a rise of 42 feet. The arch-stones are 4½ feet deep at the crown and 7 feet deep at the springers. The semicircular central arch of the Ballochmyle Viaduct, of the Glasgow South-western Railway, in Scotland, has a span of 179¾ feet. Following in the order of the width of span comes the viaduct at Nogent-sur-Marne, with nearly semicircular arches of 164.2 feet span.

Flat Arches.—Among notable flat arches are those of the Maidenhead Viaduct, with arch-radius of 169.1 feet and a rise of 27.7 feet (1 : 6.1); the Ladenburg-Neckar Bridge, with arch-radius of 95.5 feet and a rise of 13.6 feet (1 : 7); and the bridge built by Perronet at Pontoise, which, with a radius of 164.2 feet, has a rise of only 12.5 feet (1 : 13.5).

Elliptical Arches.—The earliest bridge with flat elliptical arch is the handsome Santa Trinità at Florence, built in 1566 (*pl.* 40, *fig.* 7). Other notable structures are, the London Bridge, elliptical arch, 152 feet; the bridge over the Aar at Berne, 150.5 feet; the Gloucester Bridge, over the Severn, 150 feet; the Kleinwolmsdorff, on the Saxon-Silesian Railroad, 149.7 feet; the Dora Riparia, at Turin, 148 feet; the Pont d'Alma, at Paris, 141.4 feet. The last-named is an elliptical arch built of rubble laid in cement. The earliest specimen of the basket-handle arch (a three-centred low-crowned arch) is the bridge of Châtellerault, built in 1609.

Pointed Arches.—The Gothic style of architecture, which arose about the ninth century and soon spread over Europe, gave rise to the use of the pointed arch in bridge-construction. Of bridges with pointed arches, the greater number was built prior to the close of the eleventh century. In the Middle Ages the building and maintenance of bridges were considered acts of piety, and in the twelfth and thirteenth centuries a religious fraternity styling itself the "Brothers of the Bridge" was consecrated to these objects. The bridges of Avignon, St. Esprit, and La Guillotière at Lyons, among others, were built by them.

Askew Arches.—Oblique or askew arches, whose faces are oblique to their axes, present considerable difficulties in construction, especially when the material employed for the purpose is hewn stone, because of the complicated shapes of stone required. They demand, therefore, special treatment. One form of askew arch is shown on Plate 41 (*fig.* 9).

Aqueducts and Viaducts.—The greatest elevation above the surface-level is exhibited in the ancient aqueduct of Spoleto (*fig.* 13), built twelve hundred years ago and still in an excellent state of preservation. The centre-pieces of this vast structure, which rest in the bed of a mountain-stream, have a height of 656.6 feet. Among the masterpieces of construction may be mentioned, likewise, the Roquefavour Aqueduct (*fig.* 12), near Aix, 1290.3 feet long and 265.9 feet high. The Goeltzschthal and Elsterthal viaducts, on the line of the Saxon-Bavarian State Railroad, are notable examples of recent construction.

The Goeltzschthal Viaduct (*pl.* 41, *fig.* 10), completed in 1851, is built in its main portion of four tiers of masonry arches, the central portion being formed of two large superposed arches. The total length of the viaduct is 1900.5 feet; elevation above water-surface, 263.6 feet; span of the lower central arch, 94.25 feet; height, 136.2 feet; span of upper centre arch, 101.74 feet; height from the deck-plane of the lower one, 104.5 feet. The smaller arches are built open, and the disposition of the material employed is such that the structure combines strength with lightness.

The Elsterthal Viaduct (*fig.* 11) is a two-story masonry structure. The lower story is formed of two double piers pierced with small arches, two large arches, and two retaining-walls. The length of the lower tier is 550.5 feet, and its height 110.32 feet. The central arches have a span of 95.16 feet. The upper tier has two double piers and six large cylindrical arches, each of 91.5 feet span. The total length of the upper tier is 918 feet and its height is 113.8 feet, making the total height of the structure above the water-surface 224.15 feet. The viaduct of Chaumont has a height of 164.16 feet and a length of 1986.6 feet.

In France and England the custom has been followed largely of employing for important works of this nature unbroken or continuous piers and of more or less slender proportions, copying after the pattern of the Spoleto Viaduct, above referred to. In Germany the preference has been given generally to the plan of building important structures in tiers or stories, one tier of arches being carried above another, after the pattern of the Roman aqueducts; witness the examples above noted. The lowest tier of arches is occasionally carried through only a portion of the wall, and not through its entire width (*fig.* 11, cross-section). The plan of building in tiers has been modified in the case of the Pont du Jour, over the Seine, in Paris (*figs.* 6–8). Here a double-track railway viaduct is carried on the back of a broader road-bridge, passenger travel being accommodated on a lower roadway carried through apertures pierced in the piers of the upper story of arches. The Calvine Viaduct (*fig.* 14), in Perthshire, Scotland, exhibits a form of construction in which a railway bridge crosses a highway bridge, running obliquely to its axis and at a lower level. In England, on account of the excellent quality of the cement available for building purposes, the practice of leaving large vacant spaces inside the masonry of the piers is extensively followed. On the Continent, on the other hand, the general disposition has been to give such members a compact construction.

With the founding of the corps of engineers in France, in 1720, bridge-construction received a fresh impulse. Perronet was the great master of the art in the eighteenth century. At present large bridges of stone are rarely built, on account of their excessive cost as compared with that of another type of structure, the iron bridge, which has been perfected to a remarkable degree within recent years, and which will be considered in the following section.

3. IRON BRIDGES.

Cast-iron Bridges.—The earliest iron bridges were built of cast iron, which in time gave place to wrought iron—a tougher material, and one less liable to be affected injuriously by concussion. In recent years but few large bridges have been constructed of cast iron. Among these may be named the arch bridge of Saint Louis at Paris (built in 1860–1862), with span of 210.25 feet, the Trent Bridge at Nottingham, with span of 100 feet, and certain others. In America, where iron-bridge building has reached its highest development, it is the practice to some extent to employ cast iron for such members as will be subjected to compression in the finished structure, and wrought iron for such as will be subjected to tension. The largest span (239.5 feet) among cast-iron bridges is exhibited by the Southwark arch bridge over the Thames at London.

The First Cast-iron Arch Bridge was built in 1773–1777 by Abraham Darby over the Severn at Coalbrookdale. This bridge spans the river by a single arch of 100 feet. Later (1796) there was built over the river Wear, near Sunderland, England, the Wearmouth Bridge, with an arch of open cast-iron panels, having a span of 236 feet. The most noteworthy structure of this class, however, is the cast-iron bridge built about the beginning of this century by the engineer Telford over the Spey at Craigellachie (*pl.* 47, *fig.* 1). In its form and in the distribution of material, this bridge may be regarded as the best example of the use of cast iron in bridge construction. The success of these bridges gave a decided impetus to the art of building bridges of cast iron in England, and a number of such structures—notably two at Bristol over the New Cut, one over the river Parrot at Bridgewater, and one across the Thames at Staines—were erected during the early years of the present century. In some of these, as in the Wearmouth Bridge, above named, wrought iron was used in conjunction with cast iron.

Wrought-iron Bridges may have the form of either girder, arch, or suspension bridges. Wrought-iron girder bridges exhibit great differences in construction.

Plate-iron Girders.—Where the space to be spanned is small, a simple expedient consists in riveting together two rails base to base, forming a "double-rail girder" (*pl.* 43, *figs.* 1, 2) whose ends are received in suitable cast-iron chairs, to which they are firmly clamped. Rolled beams of I-section are also very serviceable for such simple constructions, in which case the rails either lie directly upon the beams or rest upon interposed wooden cross-ties. With spans up to about 50 feet plate-iron girders may be used with advantage, the metal having a thickness of from 3/8 to 3/4 of an inch and being formed into girders of I-section by riveting (*figs.* 3, 4, 23). The rivet-bolts are inserted in the rivet-holes and clinched while white-hot. Figure 24 exhibits the appearance of the common form of rivet-bolt employed for this purpose. It consists of a head and shank in one piece. In this form, being heated white-hot in a forge-fire, it is inserted in its hole and clinched by forming a second conical head upon it through hand-hammering while it is cooling. The advantage gained by heating the rivets is not only greater ease of forming the clinching-head and the lessened liability of shattering the metal of the rivet and plate, but also a firmer union of the plates, since the contraction of the rivet on cooling draws the joined parts together more firmly than could any mechanical process. Rivet-holes in plates are drilled, not punched, as drilling avoids injury to the surrounding iron and makes a smoother hole. Figures 5 to 7 (*pl.* 43) are details of a plate-girder bridge, which exhibits the manner in which flat plates placed perpendicularly with respect to one another may be united by the use of angle-irons.

Tubular Bridges, so called, belong in this category (*figs.* 8, 9). These have high side-walls composed of a large number of iron plates riveted together and united transversely at top and bottom by a cellular structure of the same order (*fig.* 9). The first bridge of this type is believed to have been built at the Bolton Station of the Baltimore and Susquehanna Railroad by James Mulholland. This was a small structure of 55 feet span, and is noted here simply as an interesting item of history. In England and Canada there have been built upon this system truly colossal bridges which for years ranked as the greatest of their class.

The Britannia Tubular Bridge (*figs.* 8, 9), built over the Menai Strait at Bangor to carry the Chester and Holyhead Railway, was constructed by Stephenson and Fairbairn (1846–1850), and opened to railway traffic in 1850. It is composed of two continuous wrought-iron beams 1511 feet long and weighing four thousand six hundred and eighty tons each. The tubes are supported on three masonry piers and two abutments, there being thus four spans. Of these, the two channel spans are 460 feet each, and the two stone spans 230 feet each. The tubes are firmly fixed upon the centre tower, but are supported on roller-beds on the lateral piers and abutments, leaving the structure free to expand and contract.

The Conway Tubular Bridge, built over the Menai Strait by Stephenson and opened in 1848, has a span of 400 feet. The Victoria Bridge, built also by Stephenson (1859), over the St. Lawrence River at Montreal, has one span of 330 feet and twenty-four of 239 feet each.

Disadvantages of Tubular Bridges.—Tubular bridges have several disadvantages. They are exceedingly heavy and expensive, and on account of their peculiar structure are specially sensitive to changes of temperature and extremely liable to deterioration by rusting. For these reasons, as well as because of the better knowledge among engineers of the theory of strains on the members of bridge structures, and greater experience and skill in producing structural forms of iron adapted for the purpose, the tubular or solid-wall girder for wide spans has given place to the lattice- or open-work framed structures, which with equal strength are relatively much lighter, and therefore more economical. These girders (as in the case of the wooden-lattice girder) are compound beams formed of two parallel or curved upper and lower members, called "chords," connected by certain members vertical and oblique, called "web-members," which stiffen the chords and transform the various strains due to the weight of the girder itself and of its load into longitudinal strains, which by the character of the structure are conveyed up and down along the members of the girder to the piers and abutments.[1]

Framed Girder or Truss.—There are many varieties in the form and construction of bridge trusses, for each of which certain advantages are claimed. The framed girder or truss (*pl.* 42, *figs.* 1–5) consists generally of two parallel chords (an upper and a lower one) diminishing in cross-section toward the ends of the bridge. In one modification of this, the so-called "suspension-truss," devised by Bollman in the United States, there is employed a system of inclined suspension-rods uniting the feet of the posts directly with the ends of the upper chord, and therefore rendering the lower chord unnecessary. The bridge roadway with this form of truss is carried on top of the single chord, the posts and oblique ties being in this case beneath the roadway. Numerous bridges of this type exist in the United States, especially along the line of the Baltimore and Ohio Railroad. The Fink truss (*pl.* 45, *fig.* 1), also of American design, is a suspension truss of somewhat different construction, and in its original form or with certain modifications is extensively in use in the United States for railway bridges. Figures 1 to 5 (*pl.* 42) exhibit various forms of bridge trusses.

Lenticular and Bowstring Girders.—The framed girder above described may be modified by giving both chords or one of them a curved form. In the first case there results the so-called "lenticular girder" (*pl.* 44, *fig.* 4); in the last, the bowstring girder. The first specimen of the lenticular-girder bridge of which there is record was that built at Saltash, in England, by Brunel, in 1859; the two larger spans of this bridge are each 455 feet. Figure 17 (*pl.* 43) exhibits a form of the lenticular girder devised by Pauli and employed by Gerber in the construction of the iron bridge over the Rhine at Mayence (345 feet span). In the Schwedler system (*figs.* 13–15), a bowstring girder, the designer aims to economize material in the frame. In this construction the vertical web-members are in compression and the diagonals in tension.

Members subjected to tension are commonly made of flat bars; for those subjected to compression the stiffer angle-irons (⊥) or the channel form (]), are preferred (*figs.* 26, 27), or they are made of several pieces joined together by riveting to form a column of great stiffness (*fig.* 25).

[1] The following definitions from Trautwine will be found serviceable in assisting to a correct understanding of the terms employed to describe the construction of trussed structures and the functions of their members: "Most of the bridge trusses in common use have two long straight parallel upper and lower members, called the *chords* (or, in England, *booms*). Vertical pieces placed between and connecting the upper and lower chords are called *posts* when they sustain compression, and *vertical ties* or *suspension-rods*, etc., when they sustain tension or pull. The oblique pieces . . . . are called *braces*, *strut-braces*, *main braces*, etc., when resisting pressure or thrust, or *tie-braces*, *tension-braces*, *main oblique ties*, *oblique suspension-rods*, etc., when resisting pulls. Sometimes the same piece is adapted to bear both tension and compression alternately, and may then be called a *tie-strut* or a *strut-tie*. The oblique members . . . . are sometimes called main braces, whether they are struts or ties, to distinguish them from *counter-braces* or *counters*, ... which cross the main braces diagonally."—ED.

Lattice Girder.—In the earlier specimens of iron bridges the close lattice girder made of flat bars was much affected, but, as it lacked sufficient stiffness, numerous verticals were specially introduced (*pl.* 43, *fig.* 12). Present practice departs widely from this: each separate piece entering into the construction of an iron bridge serves a specific purpose and is especially adapted to resist the strains that will come upon it from the load on the structure. Some important differences exist in the practice of European and American engineers. The chief of these lies in the manner of uniting the chords to the web-members. European engineers prefer to make this attachment by riveting; in America, on the other hand, it is the universal practice to use cylindrical pins of iron or steel for this purpose. In American practice the lower chord is usually formed of flat bars placed edgewise and united by pins (*pl.* 42, *fig.* 13). The web-members subject to tension are made of iron bars (flat, square, or round) with eyes at the ends for the insertion of the pin-connections (*fig.* 8). The compression-members, which at first were made of cast iron, are now made exclusively of wrought iron or steel. They are hollow columns built up of flat pieces or curved segments of various forms riveted together. Many of the leading bridge-constructors have special forms of columns which they prefer to employ. Some of these are shown on Plate 42 (*figs.* 6, 7).

The first plate-girder, or tubular, bridge was erected in England in 1846 by Stephenson on the line of the North-western Railway. The lattice-girder and open-truss bridges constitute a later development of the art.

The Roadway of iron bridges is formed of a series of cross-beams on which are placed longitudinal pieces, and on these, in turn, rest an upper series of cross-ties or beams to receive the railway-track or the road-surface. To stiffen the bridge-structure laterally, so that it may sustain stresses due to violent storms of wind, some system of bracing is adopted, of which illustrations are shown on Plate 43 (*figs.* 18–21). If the roadway is placed on the top chord, the structure is termed a top-road (deck) bridge (*pl.* 45, *figs.* 1, 2); if on the bottom chord, it is called a bottom-road (through) bridge (*pl.* 43, *fig.* 10).

Expansion and Contraction of Iron Bridges.—Inasmuch as, in consequence of changes of temperature, the length of the bridge frame must vary, provision must be made to permit of some motion of the structure in the direction of the bridge axis. For this purpose it is customary to secure the bridge girder upon its pier or abutment at one end only, leaving the other end to rest upon a so-called "roller-bearing," upon which it may move to and fro to accommodate itself to the changes of temperature. The weight of the free end of the girder in this case is borne on hardened steel rollers, which afford the least possible resistance to its movements. For transmitting the distribution of the pressure equally to all the rollers, the "rocking-bearing" shown in Figure 16 (*pl.* 43) has proved a very serviceable device. In this, the end of the girder rests upon the rollers through the intervention of a curved bearing-plate.

Construction of Girder Bridges.—The usual practice is to construct iron bridges with each span independent, although continuous-girder bridges are not uncommon. The continuous-girder bridge affords some saving of material and can be erected without the use of staging; it is put together on the land and bodily pushed out into position on its piers, as was done in the cases of the Stadtlau Bridge over the Danube Canal at Vienna, and the Servian Railway Viaduct at Freiburg. The success of this plan, however, will depend largely upon the unalterability of the height of the piers. Should a slight sinking take place in one of these, it might seriously affect the stability of the bridge unless special provisions were made for compensating for the irregularity.

The American System claims several decided advantages—namely, it permits of the preliminary assemblage of the parts in the shop, where any defect may be observed and corrected; by the use of machines of improved construction, the lengths of the various members, the drilling of the holes for the pins, and the dimensions of the pins are controlled with the greatest possible accuracy, so that the erection of the structure may be accomplished rapidly and without demanding specially-skilled labor; the probability that the strength of the completed bridge will vary from that calculated for it must necessarily be much less than where, as in the European plan of erection first at the place of construction, there is no opportunity of determining, by preliminary trial at the shops, the existence of errors in calculation or of hidden defects; and finally, with the same strength, the American system of construction allows of a much lighter structure, representing economy of material and cost. The several advantages possessed by the American system of iron-bridge construction, as compared with that followed in Europe, have of late been freely recognized by the most eminent European authorities.[1]

[1] The subject is of so much interest that the editor may be pardoned for introducing at this point an extremely lucid and forceful exposition of the conditions which have created the diversity in practice here dwelt upon, and of the salient features and merits of American practice, from a paper of Thomas C. Clarke, an eminent civil engineer and bridge-builder, presented at the meeting of the American Institute of Mining Engineers held in Philadelphia during the Centennial year. The following extracts from this masterly review of the subject will amply cover the ground :

"Some philosopher has said that *results* come from internal impulses modified by external conditions. Applying this to European bridges, we find that the internal impulse is, *first*, to make as strong and as safe and as durable a structure as possible, and that the question of cost holds a secondary place. The external conditions are plenty of time and rivers of comparatively uniform regimen, so that there is but little danger of scaffolding being washed out by floods during erection. Hence we find, consecutively, stone arches, cast-iron arches, plate girders, and, finally, lattice girders of plates and angles riveted together, copying the proportions already established for plate girders.

"In this country, on the other hand, the internal impulse is to build the bridge—and, in fact, everything else—in as short a time as possible and for the least possible sum. Hence our railway bridges were originally made of the most abundant and cheapest material—wood—and so designed as to be put together with the utmost rapidity, inasmuch as our rivers are subject to sudden and heavy freshets and it never is safe to trust the bridge long supported by staging which may be washed out in a night. Hence, when we began to build our iron bridges, we copied the proportions already established as most economical in wooden trusses, and, instead of riveting the several parts together on the scaffolds, we adopted the use of tenons and sliding joints for the compressive members, and of pins and eye-bars for those in tension, which enables us to erect our bridges, without fitting, very rapidly.

"Having begun in this path, we have seen no reason to depart from it. We find that great economy

Notable Girder Bridges.—Among the notable wrought-iron girder bridges of the world the following may be named: The Ohio River Bridge

of material—which simply means little dead weight—is got by concentrating the iron along the lines of strain by making long panels—which means few parts—and by proportioning our girders of a depth of never less, and often more, than one-eighth of their span. The form of truss now almost universally adopted, and which, by a process of natural selection, has almost driven out of use the Bollman, Fink, and triangular girders, is the quadrangular girder with vertical posts, and main tie-bars inclined at an angle as nearly forty-five degrees as possible. This has the merit of subjecting the iron to strains in one direction only, either tension or compression; and if we agree with Herr Wöhler that iron strained both ways is as highly strained as if the tension and compression were added together, this is a point of no small importance. We prefer to hang our cross-floor beams from the pin, because then the load is transferred directly by the diagonal tie-bars without any bending moment.

"Our peculiar web system allows us to give great height to our trusses—sufficient to enable us to put in vertical transverse bracing high enough to clear the smoke-stacks of the locomotives, which, we think, adds much to the lateral stiffness of our bridges.

"The usual practice of American engineers is to provide, in addition to the weight of the structure itself, for a general rolling load of 4000 pounds per foot for spans of 50 feet and below; 50 feet to 100 feet, 3000 pounds; 100 feet to 150 feet, 2750 pounds; 150 feet to 250 feet, 2500 pounds; 250 feet to 300 feet, 2250 pounds; above 300 feet, 2000 pounds. In addition to this, the floor and panel system is strengthened to provide for a load arising from the concentrated weight of the engine of 3500 pounds, and sometimes 4000 pounds, per foot lineal. Strains in tension are taken at 10,000 pounds per square inch, and in compressions 8000 pounds to 10,000 pounds for chords of 10 to 14 diameters, and 4000 pounds to 6000 pounds for posts of 20 to 30 diameters.

"So much for the designs of our bridges. When we come to examine the methods of construction, we shall see that the marked feature is the use of special machine tools by which the sizes and lengths of all the parts are fitted with the utmost exactness at the place of manufacture. The ends of the upper chords and of the columns are faced in lathes, and the lower chord bars and diagonal tie bars are drilled with a pair of drills set on a wrought-iron bed, so as to give absolute accuracy of length. The pins are turned, and fill the holes so well that one one-hundredth of an inch is the limit of play allowed.

"Now, the point to which I particularly wish to call your attention is that when once the machinery is provided this accuracy of workmanship costs nothing. Hence there can be no disposition to slight work and make imperfect joints and bearings. The process of manufacture is the best inspection possible. The bridge is calculated to come to a certain camber; and if it does not come to that camber, or if any of the eye bars are loose, something is wrong.

"Now, every one who has ever built riveted lattice bridges knows that unless iron templates are used and the greatest possible care taken in laying out the work the rivet-holes will not come opposite to each other, and either drifting or riming must be allowed. Exactness of workmanship *can* be attained, but it costs the maker a great deal more money than rough fitting, while in the machine-made bridges there is no inducement to do poor work.

"As to the actual economy of material, perhaps the best illustration that I can give you is to quote the weights of the 200-foot spans over the Miramichi River, on the Intercolonial Railway of Canada. Tenders were received for these bridges from various European, English, and American bridge builders. There were seventeen spans of uniform length, and these were all designed on the same specification—viz., to carry a general moving load of 2800 pounds per lineal foot and a load on floor system of 3600 pounds per foot; strains in tensions, 10,000 pounds per square inch; in compression in chords, 7500 pounds to 8000 per square inch, or posts 4000 pounds to 6000 pounds.

"The different designs may be divided, for purposes of comparison, into four classes: 1. Riveted-lattice girders, short panels, 6 feet to 8 feet long; low trusses, 16 feet to 18 feet high; weights, 244½, 221, 206½, 202 tons. 2. Riveted-lattice girders, panels, 9 feet to 10½ feet long; trusses, 20 feet high; weights, 141, 140, 137, 134½ tons. 3. Pin-connected trusses, panels, 9 feet to 11 feet; trusses, 20 feet to 22 feet; weights, 128½, 126½, 122 tons. 4. Pin-connected trusses, panels, 12 feet to 14 feet long; trusses, 25 feet to 28 feet high; weights, 111, 109½, 102 tons. It will be observed that the saving of dead weight is due more to the design than to the difference between riveted and pin connections. We may say roughly that the difference due to this cause alone is nothing for spans of under 100 feet; from 100 feet to 200 feet, 5 to 20 per cent. Above 200 feet the increase is rapid in favor of pin connections. When we come to examine the question of rapidity of erection, the pin connections have a great advanof the Cincinnati Southern Railway at Cincinnati, a single span of 515 feet; the Lek River Bridge at Kuilenburg, Holland (1870), with one span of 492 feet, one of 262.5 feet, and seven of 187 feet; the Tamar Bridge at Saltash, with two spans of 455 feet and seventeen smaller spans; the Ohio River Bridge at Cincinnati, on the Newport and Cincinnati Railroad, with a span of 420 feet; the Ohio River Bridge at Louisville (1868), 5318.8 feet long and with a maximum span of 400 feet; the bridge over the Missouri River near Kansas City, with three spans of 400 feet each, one of 250, one of 200, and two of 175 feet each, and a viaduct 2000 feet long; the Vistula Bridge at Dirschau (1857), with six spans of 397 feet (*pl.* 43, *fig.* 12); the Waal Bridge at Bommel, with three spans of 393.7 feet and eight of 187 feet; the Kentucky River Bridge at Dixville, with three spans of 375 feet each; the Parkersburg and Bellaire Bridge over the Ohio for the Baltimore and Ohio Railroad, with spans of 350 feet; the Rhine Bridge (1862) at Mayence (*fig.* 17), with four spans of 345 feet and twenty-eight smaller spans; the Rhine Bridge at Hamm (1870), with four spans of 340 feet; the Rhine Bridge at Griethausen, with one span of 329.4 feet and twenty smaller spans; the bridge over Hollands-Diep at Moerdyk (1871), with fourteen spans of 328 feet each and two smaller spans; the Rhine Bridge at Cologne (1860), with four spans of 322 feet; the St. Charles Bridge over the Missouri, with channel spans of 321.5 feet; the Ohio Bridge at Steubenville, with main span of 319 feet; the Elbe Bridge at Hamburg (1870), with three spans of 316 feet; the Ohio Bridge at Benwood, with main span of 305 feet; the Wye Bridge at Chepstow (1852), with one span of 300 feet and three smaller spans; the Rhine Bridge between Mannheim and Ludwigshafen (1867), with three spans of 295 feet; the Boyne Bridge at Drogheda (1855), with one span of 267 feet and two of 140 feet each; the Danube Bridge of the Austrian North-western Railway at Vienna (1872), with four spans of 252 feet and fourteen of 97 feet; the Danube Canal Bridge at Vienna (1869),

tage. They can not only be built much quicker, but they require no skilled labor; any ordinarily intelligent laborers can erect them under a good foreman. Those of my hearers who have had the opening of their lines delayed by a strike of the riveters can appreciate this point.

"Spans up to 150 feet can be erected by a gang of twenty men in a single day, if necessary; a 200-foot span, two to three days; a 250-foot, three to four days, etc.

"As we put a less quantity of iron in our bridges, we are able to use a better quality. In fact, it is difficult to make the eye bars forged by hydraulic pressure except out of a good quality of iron.

"One more point, and I have done. In Europe I believe that the practice is to receive tenders by the pound upon detailed drawings. In the United States the engineer makes a general specification, giving the lengths of spans, width, angle of skew, if any, the loads the bridge must be designed to carry, and the limit of allowed strains, leaving all details of construction and arrangement of depth, length of panels, etc., to be determined by those competing. Different engineers, either connected with bridge establishments or acting independently, but all following that branch as a specialty, make plans in accordance with the specifications, and tender so much per foot or span, keeping the weights to themselves. These methods have their advantages and corresponding disadvantages.

"The European method, while securing plenty of iron and safety in construction, has overloaded its bridges with dead weight, and made very long spans unattainable except at great cost, from there being no competition in design. The American method has up to this time secured both a safe and an economical use of material and good quality of iron and workmanship. This has been due directly to competition in design."

250 feet; the Mississippi Bridge at Keokuk, Iowa, with main spans of 250 feet; the Danube Bridge at Stadtlau (1870), with five spans of 249 feet and ten of 110 feet; the Kinzig Bridge (1858) at Offenburg (*pl.* 43, *figs.* 10, 11), with a single span of 197 feet, etc.

Iron-trestle Bridges form one of the noteworthy varieties of the modern bridge which are made to do valuable service for railway purposes. Of these, several remarkable examples were noticed under the head of Wooden Bridges (p. 250). Some of these have been replaced by iron structures of the same type, and a number of others of exceeding boldness of design have been erected within a recent period.

Trestle Viaducts.—Of some interest are the cast-iron trestle viaducts erected over the Cheat River for the tracks of the Baltimore and Ohio Railroad. These were built in 1853 by Albert Fink. They cross the river at an elevation of 250 feet, the trestles being 60 feet high. They are still in service. The substitution of wrought iron for this form of structure is believed to have been first made by C. Shaler Smith, an eminent American engineer. He employed Phœnix columns (*pl.* 42, *fig.* 7) for posts, stiffening them with cross-struts united with diagonal tie-rods. This structure, which supported a trussed girder carrying the roadway, has been the model after which a number of similar structures have been copied. A notable example is the Portage Bridge (*pl.* 45, *fig.* 1), an iron viaduct over the Genesee River, in New York, on the line of the Erie Railway. It has ten spans of 50 feet, two of 100 feet, and one of 118 feet, and a 50-foot span placed between each of the last-named long spans.

The Verrugas Viaduct is on the line of the Oroyo Railroad, in Peru; it crosses the Agua de Verrugas at a height of 5478 feet above sea-level. As shown in Figure 2, it is composed of three iron piers respectively 145, 252, and 177 feet high, each being 50 feet long by 15 feet wide at the top. The spans are formed of trusses of the Fink pattern, three of which are 100 feet wide and the fourth 125 feet. The length of the structure over all is 575 feet.

Kinzua Viaduct.—An even more extensive structure than this is the Kinzua Viaduct, on the line of the Erie Railway, over the Kinzua gorge (*pl.* 42, *fig.* 15; *pl.* 46, *fig.* 1). It is 2052 feet in length and at its highest point 301 feet above water-level. The foundations on which the trestles are supported are piers of sandstone one hundred and twelve in number. The posts are built of Phœnix columns stiffened substantially as above described. A notable structure of the same character, 302.5 feet high and 1662 feet long, has been thrown across the Rio Pecos, in Texas, on the line of the Galveston, Harrisburg and San Antonio Railroad.

European Viaducts.—A number of notable viaducts have been built in Europe in imitation of the high wooden-trestle viaducts in this country. (See Wooden Bridges, p. 250.) Among these may be mentioned the Crumlin Viaduct (1850) at Newport, in South Wales, with trestles 173.87 feet high, and the Saône Viaduct at Freiburg (1862), with trestles 141.7 feet high. In these structures the posts and cross-struts are formed of cast iron and the diagonal tie-rods of wrought iron. This system has been followed more recently in quite a number of trestle-constructions in Europe—the Creuse Viaduct at Bousseau d'Ahun, the Cère Viaduct of the Orleans Railway, four viaducts on the Commentry-Gannat line—reaching a height of 196.8 feet—the Iglau Viaduct at Eibenschüss, etc.

In America, where this type of bridge is represented by the most remarkable structures in existence, the use of cast iron has been entirely abandoned for wrought iron, and in the United States, where iron-trestle bridges are comparatively numerous, they are made to do valuable service for railway purposes.

Steel Bridges.—Of late, steel has come into use, and a number of notable bridges have been erected of this material. The first extensive experiment with steel was in the construction of the great arch bridge over the Mississippi at St. Louis, Missouri (*pl.* 47, *fig.* 2), built from the plans of the late Captain James B. Eads between the years 1868–1874. This will be referred to under the head of Arched Bridges. A steel-girder bridge over the Missouri River between Bismarck, Missouri, and Mandan, Dakota, built for the Northern Pacific Railroad, was opened in the year 1882. It has three main spans over the river of 400 feet each, and two shore spans of 125 feet. The Lachine Bridge over the St. Lawrence at Montreal, also a notable example of a steel bridge, has a length of 3514 feet, with two main channel spans of 408 feet each, and a number of smaller ones.

Poughkeepsie Bridge.—Following the Missouri River Bridge came the great steel bridge over the Hudson at Poughkeepsie (*pl.* 46, *fig.* 4), finished in 1888. This fine structure has a total length of 6667 feet. It has three spans of 540 feet each and two connection spans of 525 feet each. At the present time this bridge has the longest span of any structure of its type. This structure is a most important one in its relation to the transportation system of an extensive region, forming as it does the connecting-link required to establish direct communication between the railway systems of the New England States and those tapping the coal-fields of Pennsylvania.

Cantilever Bridges.—Of late years bridges constructed on the principle of the cantilever—that is, in which the superstructure is formed of projecting beams or levers fixed at one end to the abutments or piers and free at the other end—have come into high favor among engineers. This type of bridge structure, like the suspension type to be later considered, is an ancient one, and its revival is due principally to American bridge-builders who have adopted the system successfully in the case of a number of important structures.

Ancient Japanese Cantilever Bridge.—An interesting example of a bridge on the cantilever principle, which is of undoubtedly high though of unknown antiquity, is shown on Plate 38 (*fig.* 7). The existence of this structure was made known to the engineering world through a correspondent of Van Nostrand's *Engineering Magazine*, who furnished a photograph of the bridge, on which the Figure is based, and also a brief description, which is here substantially reproduced. The picture is a view of a very fine and costly bridge of red lacquered work, of cantilever construction, built by native engineers at the sacred city of Nikko, in Japan. "The abutments are of hewn stone, the shore piers of hewn granite, octagonal, monolithic, mortised for stone girders; monolithic plate beams receive the wooden superstructure. The stringers, which are fastened into the abutments, balance over the stone beams, but do not reach, by a considerable distance, the gap being fitted by middle stringers let into the shore stringers. The Niagara Bridge is a mere amplification of this one, which was built as a religious duty, and, like a bridge of angels, its planks are never profaned by the feet of the laity."

Pope's Flying-lever Bridge.—In a now somewhat scarce work by Thomas Pope, published in 1811, with the title *A Treatise on Bridge Architecture, in which the Superior Advantages of the Flying Pendant-lever Bridge are fully Proved*, etc., the author describes a method of constructing a timber or iron bridge "with a single arc, on the principle of the lever." This plan is identical in principle with what is now designated the cantilever. Pope prepared detailed plans and estimates for the erection of a timber bridge on this system across the East River at New York, and constructed a model to illustrate the practicability of his ideas. In his treatise there occurs, in a foot-note, the following reference to this model. It "was built to illustrate a bridge suitable to span the East River at New York with a single arc the chord of which would be 1800 feet; the altitude, or versed-sine, 223 feet. The abutments were built in the form of so many warehouses, and the whole was erected on a scale of 3/8 of an inch to one foot; the length of model of half bridge, in real measure, is nearly 50 feet. The weight borne at one time by the unsupported arm of this diminutive model, since finished, has been ten tons, and has astonished the mind of every beholder." This ingenious man, like others who think in advance of their time, failed to see his plans realized. Figures 5 and 6 (*pl.* 38) are illustrations of this unique project, which is worthy of record because of its historic interest.

Niagara Falls Cantilever Bridge.—One of the most interesting specimens of the cantilever bridge is exhibited by the beautiful structure spanning the Niagara River a short distance below the Falls (see *Frontispiece*). It has a total length of 910 feet and crosses the river with a single span of 470 feet; the roadway is 239 feet above the water-level. On account of its great height, as well as the rapid current of the river at this point, the erection of staging in the stream was impossible, and the mode of building by "overhang" (described in the reference to the Forth Bridge) was adopted. The materials employed are steel and iron.

Firth of Forth Bridge.—The Poughkeepsie Bridge will be far exceeded in length by the great steel bridge now in course of erection over the Firth of Forth at Queensferry, in Scotland. This colossal structure, the design of which is shown on Plate 46 (*figs.* 2, 3), with viaducts, will be 8300 feet long, with two main spans of 1700 feet each and two side spans of 675 feet each, with a clear way between water-level and the central 500 feet of 150 feet. Each span consists of two cantilevers joined by a central girder. The method of building is that known as "erection by overhang"—that is to say, each of the great cantilevers will be built out like wings from the piers, section by section, until they shall have been advanced far enough to be united to their connecting girders.

Combination Bridges, constructed in part of wood and in part of iron, are in vogue in the United States to a considerable extent for railroad bridges on account of their cheapness. The practice is to construct the members subject to tension of wrought iron and the compression-members of wood, the connections being either of cast or wrought iron. They are adapted for spans up to 200 feet.

St. Paul Highway Bridge.—The structure shown in Figure 2 (*pl.* 44) is a truss bridge which spans the Mississippi River at St. Paul. It is a highway bridge, and is constructed of a series of trusses, of which the largest, the channel span, is of iron, the remainder being of wood. The peculiar feature of this bridge resides in the fact that its roadway is built upon a grade of 1 : 20 up to the channel span, where it is 1 : 28—an arrangement that is made necessary by reason of the bluffs (125 feet high) on the west bank of the river. The eastern approach is formed by an embankment 1500 feet long, followed by 375 feet of trestle-work in bents 30 feet apart. Then follow seven spans of 140 feet each, succeeded by the channel spans of 240 feet and a short span of 80 feet, over the St. Paul and Omaha Railroad to the top of the bluff. The piers are built in steps, so that there is a difference of 7 feet in the height of each succeeding one, and the roadway is supported on the top chords by bents. The short spans are of wood. The channel span is of iron, and gives a clear headway of 63 feet above high-water level.

Girard Avenue Bridge.—One of the most celebrated roadway structures of its kind is the Girard Avenue Bridge across the Schuylkill River at Philadelphia. It has five spans, with a total length of 865 feet, and the width of the roadway is 100 feet, divided into one carriage-way of 67½ feet and two sidewalks each of 16¼ feet. This bridge is remarkable as the first attempt in this country to combine the American system of pin-connection bridges with a solid roadway of stone.

Wrought-iron Arch Bridges, in use some thirty or forty years for roadway bridges, have of late come into vogue for railway purposes; they are, as a class, remarkably handsome structures (*pl.* 43, *fig.* 20). The arch is constructed either as a plate girder or as an open girder. Provision is made for the slight distortion and lateral displacement of the arch girder by reason of stress produced by the load and by changes of temperature. For this purpose the feet of the arches, which rest upon the piers, are not rigidly joined to the latter, but by some form of interposed bearing which will permit of a slight degree of play (*fig.* 22). By introducing a third joint at the crown of the arch the latter may without resistance adjust itself to the changes of temperature by expanding or contracting, in consequence of which the crown of the arch will rise and fall very slightly.

St. Louis Bridge.—The most important structure of this type, and one of the most imposing bridge structures in the world, is the steel tubular-arch bridge over the Mississippi at St. Louis. It has three spans, each formed with ribbed arches of cast steel. The centre span is 520 feet wide, and the side spans are 502 feet (*pl.* 47, *fig.* 2). The piers and abutments rest at considerable depth on rock-foundation, which was secured by the use of caissons with air-chambers and locks. The bridge was completed at a cost of ten million dollars, and opened for traffic in 1874.

Douro River Bridge.—An iron-arch bridge of bold and noble design is that over the Douro River near Oporto, Portugal (*fig.* 4). This structure was finished in 1877. It is 1511 feet long, and spans the river with a single arch 520 feet wide, with a height above the water of 198 feet. The piers are iron trestles resting on granite foundations. The lower platform is divided into five bays by the suspension-rods. It is formed of two lattice girders spaced 29½ feet apart from axis to axis and 10½ feet wide between the chords. The main girders have been strengthened, with the view of resisting the wind; so that the platform alone, without the aid of the rigidity of the suspension-rods, is amply strong for the purpose, the construction being such that the stress due to the wind is transmitted directly to the abutments, where, against the masonry, are arranged shoes which permit of expansion, but prevent all lateral motion.

Harlem River Bridge.—At the present time a steel-arch viaduct of two spans is being constructed over the Harlem River, New York (*fig.* 3). These arches are plate girders of steel, having each a span of 510 feet. They rest on massive masonry piers, which rise to the level of the roadway, which, in turn, is supported on vertical posts erected on the arches. The height is 152 feet above the water-surface. The approaches are viaducts of granite carried on stone arches.

Other Noteworthy Iron-arch Bridges are the Rhine Bridge at Coblenz (*pl.* 43, *figs.* 20–27), completed in 1864, with three spans of 317.3 feet width; the Hôtel de Ville Bridge in Paris, with a span of 262.5 feet; the drawbridge at Marburg, with three spans of 172.3 feet; the Theiss Bridge at Szegedin (1858), with eight spans of 138.8 feet; the railway bridge over the canal St. Denis (1858), with a span of 148.3 feet; the street bridge over the canal St. Denis at Villette (1867), with a span of 147.7 feet; the Ruhr Bridge at Mühlheim, with three channel spans of 118.5 feet, etc. What is believed to have been the first wrought-iron arch bridge was built over the Cron at St. Denis (1808).

Suspension Bridges have as their prototypes the crude rope bridges known to the natives of Hindustan and South America and to the Chinese from time immemorial. These were formed of a couple of ropes or twisted vines (lianas) thrown across a river or precipice, with a roadway of bamboo or the like lashed to them; other ropes stretched across the space at suitable height above those first named formed hand-rails. Figure 3 (*pl.* 38) exhibits one of these primitive bridges in the Himalaya Mountains. It is made of two parallel canes, resting at their ends on posts, and from these are suspended loops at intervals in which the floor of cane is laid. This particular structure spans the Runject near Darjiling, and is 240 feet long.

In the suspension bridges proper (*pl.* 41, *figs.* 1, 2; *pl.* 48, *figs.* 2–4) the roadway is not placed directly upon the cables or chains, but is suspended from these by means of suspension-rods and stays. The form and inclination of the roadway, therefore, are quite independent of the cables or chains, and in recent bridges of this type it is customary to give the roadway an inclination upward from both ends toward the middle of the span.

Classes of Suspension Bridges: Construction.—Suspension bridges may be of two kinds—chain bridges and wire-rope or cable bridges. In those of the first class (*pl.* 41, *fig.* 3) the chains are formed of rods or bars of forged iron or steel, of which a number—as many as twelve—placed side by side, form a link of the chain. These rods have at their extremities eyes through which bolts or pins are passed, fastening them to one another, and with which the suspension-rods supporting the roadway are likewise secured. Frequently two chains (as in the Figure) are used, one over the other.

The earliest wrought-iron chain bridges of which there is record were those built by Finlay in the United States. The supporting structure in these was a chain formed of 7-foot links of square bar-iron, from which the roadway (of wood) was hung by iron suspension-rods. The towers were generally of wood. The first of these chain bridges was the road bridge with a span of 70 feet built in 1796–97 over Jacob's Creek on the highway between Uniontown and Greensburg, Pennsylvania. The general appearance of these bridges is shown on Plate 48 (*fig.* 1).

In the wire-rope or cable bridges (*pl.* 41, *figs.* 1, 2; *pl.* 48, *figs.* 2, 3), instead of the above-described iron or steel links, many strands of iron or steel wire are laid up to form a cable, which is finally firmly bound round with wire. One of the first (if not the first) cable suspension bridges in the United States was that built in 1842 by Charles Ellett, Jr., over the Schuylkill River at Fairmount, Philadelphia. It was in its time quite a noted structure. It had ten cables, five on each side, and the span from centre to centre of towers was 358 feet. The clear width between side rails was 25 feet. This bridge remained in service for about thirty years, when it was replaced by the present double-deck bridge of iron.

Anchorages and Bearings.—The chains or cables may be anchored directly to a rock anchorage, or, as is almost universally done, may be extended backward over piers or towers and firmly secured to the solid rock or beneath a mass of masonry by means of "anchor-plates" (*pl.* 41, *figs.* 5*a–c*; *pl.* 42, *fig.* 9). The anchorage must, of course, be amply strong to resist the pull of the cables. That the slight movement of the cables proceeding from changes of loading and of temperature may not exert an injurious bending strain upon the towers, it is necessary that the bearings on which the cables rest shall be such as will allow the cables a certain freedom of motion. Figure 4*a*, *b* (*pl.* 41) and Figure 10 (*pl.* 42) exhibit some of the numerous artifices employed for this purpose. In these devices the cables rest upon movable saddles with a gentle curvature to avoid a sharp bend, and the saddles, in turn, rest upon a series of horizontal steel rollers which are free to move in response to the action of the cables. The under-bearing is a flat plate of iron or steel fastened by bolts to the top of the pier.

The Advantage of Suspension Bridges over the girder and arch bridges is that the supporting structures (the chains or wire cables) are subjected to strains of tension only, in consequence of which a much lighter construction for a given load is made possible than with bridges of other types. For the same reason, bridges of this type may be successfully employed for spans of great width where other forms of bridge could not possibly be employed. The number of intermediate piers is reduced to a minimum in the suspension system, which means a saving in cost and a lessening of the obstruction to the waterway. The construction of the suspension bridge, also, whenever the cables or chains are in place and secured to their anchorages, is a simple matter, as the scaffolding required for the erection of the rest of the structure is comparatively light, and can be suspended from the cables and moved along as the work progresses.

The Disadvantage of Suspension Bridges, on the other hand, is that in high winds or in the passage of heavy loads they are liable to deformation and to more or less severe oscillation, in consequence of which they have been confined principally to ordinary road traffic and are used only to a limited extent for railway traffic.

To stiffen the structure and give it greater stability, several plans have been adopted. One is to make the suspended superstructure a trussed girder, and, in addition to this, to steady the structure by the use of anchor-rods or wire ropes which are attached at different points under the floor, and are carried to the abutments and firmly fastened to them. This plan is adopted in the railway suspension bridge built over the Niagara River by Roebling (1852–1855; *pl.* 48, *fig.* 2). A different plan is adopted in the "Point Bridge," at Pittsburgh (*fig.* 4). This is a chain bridge, in which the chain itself is stiffened by a truss and jointed at the centre and piers. A somewhat similar plan is employed in the railway bridge over the Danube Canal at Vienna. To secure additional lateral stiffness to resist wind-pressure, it is usual to draw the cables inward at the centre of the span. In the Niagara Falls Suspension Bridge, which has four cables—two on each side of the bridge—the two upper ones are 37 feet apart where they rest on the towers and only 13 feet apart at the centre, while the lower set are 39 feet apart at the towers and 25 feet at the centre.

Where, in addition to the cables at the sides, there are others placed over the axis of the bridge, as is the case in some wide bridges of this type, it is the practice to draw the outer cables inward at the centre of the span as just noted, and to spread the inner cables at the centre and draw them in at the piers. To stiffen the roadway and lessen undulations and relieve the cables of much of the strain they would otherwise have to sustain, a number of wire rods or cables, called cable-stays, are used. These extend from the saddles obliquely downward, and are attached to the floor. These stays may reach out a considerable distance across the span. They serve an excellent purpose in transmitting directly to the saddles the strain due to the weight of the structure and the load (*pl.* 41, *fig.* 1).

In the Ordish-Lefeuvre system, illustrated in the Franz-Joseph Suspension Bridge, at Prague, the plate-girders of the roadway are supported entirely by such oblique suspension-rods passing directly to the towers; and as, on account of their great length, they require stiffening, they are fastened to a comparatively light chain, passing from tower to tower, by means of vertical suspension-rods.

East River Suspension Bridge.—The greatest existing structure of this type is the suspension bridge over the East River joining New York City and Brooklyn (*pl.* 48, *fig.* 3). It crosses the river with a single span of 1595 feet. The approaches, which are heavy masonry arches, are 2492.5 feet long on the New York side and 1901 feet on the Brooklyn side, making the total length of the structure 5989 feet. The bridge has a clear headway at high tide of 135 feet at centre and of 120 feet at the ends. The cables are four in number, each 15.5 inches in diameter. The piers are 134 feet long and 56 wide at the water-line, and rise to the height of 280 feet. Each is pierced with two pointed arches for the admission of a railway track, carriage- and foot-way (*pl.* 42, *fig.* 11). As above stated, the two outer cables are drawn in toward the centre, and the two inner ones are spread outward, to stiffen the structure against wind-pressure. This splendid structure was designed by John A. Roebling, and was completed by his son, Washington A. Roebling. It was opened for traffic in 1883. Figures 9 to 12 exhibit a section of the roadway and certain other details of interest.

Other Notable American Suspension Bridges.—Many other notable structures of this type, and some of the largest of their kind, are to be seen in the United States. Of these may be named the Clifton Bridge,[1] at Niagara Falls (for foot-passengers), with a span of 1268.3 feet (1869); the Ohio River Bridge between Cincinnati and Covington, Kentucky (*pl.* 41, *figs.* 1, 2), built by the elder Roebling (1867), with a span of 1057 feet between the towers, with two cables only, and a clear headway at low water of 103 feet at centre and of 91 feet at the towers. The total length, including approaches, is 2252 feet. Another interesting specimen of this type of structure is the Niagara Falls Railway Suspension Bridge (*pl.* 48, *fig.* 2), completed by the same eminent constructor in 1855. The span is 821 feet and the height above the water-surface 245 feet. There are four cables, which rest on two iron towers at each end, 60 feet high, the towers resting, in turn, on substantial masonry foundations. The superstructure

[1] Destroyed by a violent wind-storm January 5, 1889.

is in the form of a rectangular box 18 feet deep and 24 feet wide, the sides being formed of an open-trussed girder. The top or upper floor of the superstructure carries the railway-track, and the bottom or lower floor is the foot- and carriage-way. The Point Bridge over the Monongahela River at Pittsburgh (referred to above) is interesting because of certain peculiarities of construction. This is a chain bridge of three spans, the longest being 800 feet (*pl.* 48, *fig.* 4).

Notable European Suspension Bridges.—Among the noteworthy European suspension bridges may be named the cable bridge over the valley of the Saône at Freiburg (1832), with a span of 195.7 feet; the Danube Bridge. between Pesth and Ofen (1845), with a central span of 666 feet and two lateral spans of 298 feet; the Hungerford Bridge over the Thames at London (1845), with three spans of 676 feet and two of 329.5 feet; the cable bridge over the Vilaine at Roche-Bernard, with a span of 664 feet; the chain bridge over the Menai Straits at Bangor (1826), with a span of 578.5 feet (*pl.* 43, *fig.* 8); the Franz-Joseph Bridge over the Moldau at Prague (1868), with a central span of 480.3 feet and two lateral spans of 156.5 feet each; the Franzens Chain Bridge over the same river at Prague (1842), with spans of 433.4 and 109 feet respectively; the Albert Suspension Bridge over the Thames at Chelsea, with a centre span of 400 feet and two side spans of 155 feet each; the Hammersmith Bridge over the Thames in London (1827), with three spans of 399.5 feet each and two of 147.3 feet; the Dordogne Bridge at Cubzac (1839), with spans of 357.6 feet; the Maas Bridge at Seraing (1843), with a span of 344.5 feet; and the Conway Chain Bridge over the Menai Straits (1826), with a span of 327 feet.

Royal Gorge Bridge.—The ingenuity with which American bridge engineers overcome obstacles of an unusual character by departing from traditional custom is well illustrated in the original design of the bridge carrying the line of the Denver and Rio Grande Railroad over the Royal Gorge of the Arkansas River in Colorado (*pl.* 44, *fig.* 3). At this point the walls of the cañon rise almost vertically to the height of 1800 feet, and the difficulties of making a roadway into the mountain-side by blasting were so great that it was determined to bridge the space to be crossed by the railroad. This was accomplished by suspending the superstructure by means of rods from two "arch-braces" or rafters braced against the walls of the gorge. The superstructure is a plate girder 7 feet deep, and in three spans with a total length of 275 feet. It spans the gorge at a height of 47 feet above the water-surface. The structure was designed and built by C. Shaler Smith.

Bridge Piers.—In modern times piers of iron are not infrequently used in situations where it is desired to economize space beneath the bridge, or where it is important to reduce to a minimum the load upon the foundation, or, finally, where their use affords the most convenient mode of obtaining a good foundation. (See p. 286.) Where the structure is raised to a considerable height above the surface, iron piers are cheaper than those of stone.

Piers of Cast Iron are either in the form of columns, of which one or two rows resting on low stone foundations are placed directly under the girders, or they consist of separate tubular pillars or columns driven into the ground to a solid foundation either by arming the foot of the column with a screw (*pl.* 50, *fig.* 11) and screwing them down, or by washing out the earth, sand, etc., beneath them with the aid of a water-jet, etc.; or, finally, they are tubular piers formed of cylindrical sections fastened together with screw-bolts passing through inside flanges. These sections are added one after another as the cylinder is sunk to its foundation. This is accomplished by either the vacuum or the plenum process.

Sinking Piers: Vacuum Process.—In the vacuum process the air is exhausted from the interior of the cylinder, when its own weight, aided by atmospheric pressure, causes it to sink a certain depth, and the external pressure forces the soft soil around the open bottom of the cylinder up into its interior. The air is now admitted and this soil is taken out. The cylinder is then closed above, again exhausted of air, etc., and this is repeated until the bottom of the cylinder has reached a sufficiently solid foundation.

The Plenum Process is the reverse of this. The water is forced out from around the bottom of the cylinder by forcing air into it; and when empty, men are sent down into it (through an air-lock, *pl.* 50, *fig.* 12, to keep the pressure intact), who remove the soil from around the bottom and to some distance below it. When they have left the chamber, the pressure is withdrawn, and the cylinder, no longer sustained by the upward pressure of the compressed air under its closed top, sinks to the depth of the excavation made below its foot. Air is again forced into the chamber and the same series of operations repeated until the desired solid foundation is reached. This principle—modified in details—was adopted in the construction of the South Street Bridge over the Schuylkill at Philadelphia (*pl.* 50, *fig.* 13). The diameter of the cylinders should be such that for a double-track bridge each pier should be formed of two, or at most of three, such cylinders. To diminish the liability to further settlement under the weight of the bridge, as well as to increase the resistance of the iron to concussion, the interior of the cylinders is filled with concrete. Finally, it may be mentioned that in certain cases the towers of suspension bridges (the Dordogne Bridge at Cubzac, 1839) and the piers of high viaducts (St. Gall Bridge, 154.8 feet high) are constructed of cast iron in the form of tiers or trestles.

4. Movable Bridges.

Classification.—When, by reason of the insufficient height of a bridge structure thrown across a river or other stream, navigation is obstructed, means must be employed whereby the bridge may be opened to permit the passage of vessels. This is accomplished through various mechanical artifices by whose aid either the entire bridge (where its length is small) or a section of it is lifted by chains (lift bridge), or slid back (rolling bridge), or made to revolve upon a vertical axis (pivot bridge), so that the length of the movable section is placed parallel with the channel of the stream.

Lift Bridges.—In the lift bridges a section of the bridge floor is raised to a vertical position by the aid of some simple mechanical device, such as a windlass secured to some stationary part of the structure and connected with the movable section by a rope or chain. A counter-weight is frequently used for this purpose, with suitable provision for counteracting the difference in leverage during operation (*pl.* 49, *fig.* 2). This form of movable bridge is adapted only for small structures, such as those spanning creeks, canals, or ferries.

Rolling Bridges.—In the rolling bridges the moving section is mounted upon cylindrical rollers, by which the friction of the parts is reduced to a minimum.

Pivot Bridges.—In the pivot bridges, which are by far the most numerous of this class, the centre bearing is formed of a series of short conical rollers arranged radially in a circle in such a manner that the vertices of the cones, when extended, will intersect at the turning-point or pivot of the draw-span. The draw is turned usually by means of a toothed wheel which is geared into a rack on the centre ring, and which is operated by a capstan worked either by hand or, in the case of a structure of great size, by a steam-engine. The movement of the draw-span is controlled by some form of locking device which prevents it from passing beyond a predetermined limit.

Arthur Kill Drawbridge.—The recently-constructed drawbridge spanning the Arthur Kill and connecting the States of New York and New Jersey is worthy of notice, as it is at present the largest drawbridge in existence. Figure 1 (*pl.* 49) shows this structure with the draw open. The total length of the bridge proper, exclusive of approaches, is 800 feet. It comprises two shore spans covered by fixed trusses, and two draw spans closed by the great drawbridge, which has a total length of 500 feet. On each side of its central pier it affords, when open, a clear waterway of 208 feet. It requires about two minutes to open or to close it. This structure was completed in August, 1888.

Pontoon Bridges.—Floating or pontoon bridges, consisting of a number of floating and anchored vessels (boats or pontoons), designed to serve as the support for a roadway across a stream, are of great antiquity. The army of Darius crossed the Bosphorus (493 B. C.) on a bridge of this kind on its way to invade Greece, and his successor, Xerxes, crossed the Hellespont (480 B. C.) in the same manner. Pontoon bridges were also used by the Romans in their campaigns. In modern times they have acquired importance in connection with military operations, and the armies of various nations have a trained organization (bridge-equipment corps) to facilitate the passage of rivers. For this purpose the corps is provided with various forms of portable floating pontoons and appurtenances, by whose aid a stream of considerable width may be bridged in a few hours with a temporary structure sufficiently strong to bear any weight which would be likely to be brought upon it in service. A number of bridges of this type are in use at the present time for ordinary road traffic, and recently they have even been made to serve for railway traffic, as in the case of the railway pontoon bridge over the Rhine at Maxau, built in 1865 (*pl.* 39, *fig.* 14), the roadway of which is supported upon thirty-four pontoons. Including approaches, it is 1190.3 feet long, and is traversed with light locomotives. To permit of the passage of vessels plying the river, certain sections are detachable, so that they may be swung open and closed, as may be required.

Pontoon Drawbridge.—What is said to be the largest structure of this class in the world is the pontoon drawbridge over the Missouri River at Nebraska City, of which a view is shown in Figure 5 (*pl.* 47). Its length across the navigable channel is 1074 feet, while the back channel is traversed by a causeway 1050 feet long supported on cribs. The draw is V-shaped, with the apex down stream. It is operated by the current and controlled by one man. The clear span of the draw is 528 feet. It was completed and opened for traffic in August, 1888. It will be removed during the ice season.

Flying Bridges (ferries) are employed in situations where the traffic is not important enough to warrant the erection of a bridge. They consist of a boat or pontoon (or of two coupled boats) and the cable to which it is attached and by which it is guided from side to side of the stream. A cable is sometimes stretched across the stream from bank to bank, and the towing rope for the boat is attached to this by means of a travelling roller (*pl.* 39, *fig.* 18), or, more commonly, the cable is anchored in mid-stream, so that it is free to swing around its fastening when the boat, which is secured to its other end, crosses over (*fig.* 19). To support the cable, so that it shall not drag along the bottom of the stream, it is attached along its course to several floats or trailing pontoons. The boat is propelled across stream by the force of the current against its side, which is kept diagonally to the course of the stream, while the head of the boat is kept in the right direction either by the rudder or by a chain secured to the towing cable.

Rolling Bridge at St. Malo.—A novel system of communication, that is sufficiently interesting to warrant notice, is the rolling bridge between the two cities of St. Malo and St. Servan, situated on the northern coast of France, on the English Channel, and separated from each other by a narrow arm of the Channel, which is dry at low tide, but quite deep at high tide. To establish direct intercourse between the two cities the architect Leroyer of St. Malo constructed a light iron framework which carried foot-passengers from one jetty to another. This iron structure rests upon a carriage mounted on wheels adapted to run on a railway-track. The carriage is drawn in one direction or another by attached chains, which wind over a drum actuated by a steam-engine. At the upper part of the framework there is a platform for carriages, wagons, and merchandise, and for the convenience of foot-passengers there is provided a species of cabin, to serve as a protection from the weather. The bridge operates at all states of the tide. At high tide the appearance of the structure moving across the waterway with nothing visible above the water but the freighted platform and a few slender iron rods of the framework is quite curious. At low tide the passage-way is dry, and the appearance of the bridge making its trip between the jetties is shown in Figure 3 (*pl.* 49). The height of the platform floor above the rails is 34½ feet, and at high tide the bridge is submerged to the depth of 33 feet. The distance to be traversed from side to side of the pass is 295 feet, and the trip is made in two and a half minutes. This rolling bridge has been in operation since 1871 without interruption. The system is an exceedingly simple one, and, as there would appear to be no difficulty in extending it considerably in length, it might be found a serviceable expedient for other localities where the conditions are similar.

Railway Ferries serve for the transportation of railway trains (excluding the locomotive) across rivers, lakes, etc., whereby the unloading and reloading of freight or the transfer of passengers is avoided. They are boats of various dimensions, with a deck provided with several railway-tracks, upon which sections of a train are run from the wharf. This species of railway ferriage is used in situations where the building of a bridge is inexpedient for economic or strategic reasons, or to provide facilities for transportation pending the construction of large bridges. These railway ferries may be divided into two classes: (1) Those in which the ferry-boat is steered by its rudder, and is therefore free to follow any course; and (2) Those in which the course of the ferry-boat is directed to the desired point by means of a chain or wire rope. In those of the first class either the rails are placed upon the steam ferry-boat itself or the cars are run upon tracks on special flat-boats, which the ferry-boat conveys to their destination. In those of the second class, where the course of the boat is fixed, the boat traverses the stream with the aid of two chains laid on the bed of the stream and anchored at the ends. Chain-wheels on the boat driven by a steam-engine pick up the chains, and in this manner the boat propels itself to its destination. The chains are paid out as the boat progresses, and sink again to the bed of the stream.

The Rheinhausen-Hochfeld Ferry of the Rhenish Railway (*pl.* 39, *figs.* 15–17), on account of the shallowness of the river and the irregularities of its bed, has two wire-rope cables substituted in place of the chains; of these one of 1.8 inches diameter serves as a guide-cable, and the other of 1.14 inches diameter serves as the working rope. The guiding cable is passed over two guide-pulleys placed near the front and rear of the ferry-boat and slightly above the water-surface. It is held in place by anchor-chains attached at intervals of about 125 feet, their attachment to the cable being made in such a manner as to interpose no obstacle to its passage over the guide-pulleys (*fig.* 16). The working cable is passed over two winding-drums upon the ferry-boat, and these are set in motion by a small steam-engine, and the working rope, like the guide-rope, is fastened at the shore ends to a suitable anchorage. The section and plan views in Figure 20 (*pl.* 39) illustrate this system very clearly.

Mode of Transfer on Railway Ferries.—The means by which the cars are transferred to and from the terminal stations—always situated well above high-water mark—to the lower-lying boat's deck, the height of which will vary according to the height of the water and the weight of the load it carries, may be classed as follows: (1) Those in which the difference in level is accommodated by interposed inclined planes; and (2) Those in which the difference in elevation is eliminated by raising or lowering the cars, by moving either the platform on which they stand or the boat itself vertically up or down, as may be necessary.

Transfer by Inclined Planes.—At the ferry of the Rhenish Railway communication between the ferry-boat and the river-bank is established by the intervention of inclined planes (incline, 1 : 48), which are carried from the level of the terminal station to a point below low-water mark (*pl.* 39, *figs.* 15, 17). In this case the locomotive may be used directly to draw up the cars. A transfer platform or bridge mounted on wheels and running on the ordinary rails (*fig.* 17) is used for shifting the cars from the boat to the shore, and *vice versa.* In order that this connecting bridge may be kept as short as possible, it is given an upward inclination toward the comparatively low-lying boat's deck. Simple means are provided by which the boat and shifting-bridge are held in position while the transfer is being effected. The locomotive is not permitted to run upon the bridge, and to avoid the necessity of this two empty cars are interposed between the locomotive and the cars to be transferred (*figs.* 15, 17).

Transfer by Vertical Movements.—An illustration of the second order of transfer devices, in which the transfer is effected by direct vertical movements, is afforded in the case of the railway ferry between Homburg and Ruhrort, where the cars are run upon iron platforms which may be raised or lowered through a distance of about 28 feet by hydraulic power. On the Lake of Constance another plan of this order is in use, in which the ferry-boat itself is raised or lowered, as may be necessary, by admitting or pumping out the needful amount of water-ballast. This plan is suitable only in situations where the alterations of the water-level are slight, as in this case.

Movable-deck Transfer Ferryboat.—Figure 2 (*pl.* 51) is a cross-section of a steam ferryboat whose deck, designed to provide for landing at any state of the tide, is capable of considerable movement. The usual movable landing-stage is dispensed with; the deck of the boat is a platform operated by six hydraulic elevators, by which it can be elevated or depressed, as may be required. The illustration shows the boat with the deck raised to the quay level at low tide. The landing is made at the side of the boat, but the same principle could be applied to provide an end landing should this be desirable.

Bridge Construction in the United States.—In conclusion of this section, the editor is enabled to append, on the authority of Thomas C. Clarke, an estimate of the total amount of bridge construction in the United States. It would be instructive to place beside this a similar estimate respecting bridge structures of European countries, but data for this unfortunately are not at this time accessible. Mr. Clarke estimates approximately that there are in the United States, at the present time (1888), 208,749 bridges of all kinds, having an aggregate length of 3213 miles. These are composed of

Iron- and wooden-truss bridges,	61,562 spans, with a total length of	1086 miles.
Wooden trestles	147,187 " " " "	2127 "
Totals	208,749	3213 miles.

IV. HYDRAULIC ENGINEERING.

As the earliest works for the protection of the land from overflow by water grew out of the necessity of guarding the settlements and the habitations of mankind from destruction by inundations, so the necessity of supplying vegetation with the water needful for its growth gave rise to the construction of works for providing artificial supplies of this element, and for the irrigating of districts naturally destitute of it or whose supplies were uncertain in quantity; and so, likewise, the desire to transform unwholesome and useless marsh-lands into fertile fields and to reclaim from the waters lands suited for agricultural purposes originated extensive works for drainage.

With advancing culture, communication by water increased, and to facilitate the navigation of streams various works for their regulation and correction became necessary. Navigable canals were at length constructed, establishing, by convenient water highways, communication between rivers or between rivers and distant oceans and their ports. The ever-increasing population of cities and towns in time rendered it necessary to provide extensive hydraulic constructions in the form of aqueducts, canals, etc. for conducting and distributing their water-supplies, and the rapid growth of the industries called into existence many forms of construction and appliances for utilizing water as a motive-power. Finally, the execution of the various works—such as bridges, aqueducts, locks, and the like—needed in the construction of roads, railways, canals, etc., has demanded the invention and perfection of many modes of securing artificial foundations, which are sufficiently important to constitute of themselves a special branch of hydraulic engineering, to the consideration of which the reader's attention is invited.

1. FOUNDATIONS.

The choice of the method to be employed in laying a foundation depends chiefly on the nature of the ground, and the distinction may be made between good ground (such as rock, gravel, sand, and firm clay), medium ground (such as loam, dry peat, light clayey and meadow soils), and bad ground (such as wet clay, marshy and boggy soils, quicksand, etc.). The less compressible the soil and the less it is affected by the action of water, the better it is suited for foundations. To avoid injury from frost, the base of the foundation should be carried below the frost-line.

Dry Foundation.—Where the foundation is not reached by water and may be laid dry, the work resolves itself simply into the excavation of a suitable pit or trench or a series of pits and trenches, according to the nature of the work, to the depth of 3 or 5 feet (for ordinary work) where it has been ascertained that the surface soil is reliable. The bottom of the excavation must be properly levelled, and in disposing the blocks of masonry constituting the foundation the largest stones should be placed at the bottom. In the case of foundations made in soil the base should be broadened, to insure the proper distribution of the pressure. In such cases, also, care must be taken that the stones of the bottom course are solidly bedded in the ground, so that they shall not exhibit any tendency to displacement when loaded with the weight of the masonry laid upon them.

Foundations in Unstable Ground.—If a firm bottom can be found only at a considerable depth, it will be necessary, in the case of large and heavy constructions, to excavate the overlying soil until solid ground is reached; where the weight of the intended structure is not very great, it will often suffice to found it upon separate pillars or piles of stone or iron united above by arches or girders and reaching down to the solid bottom. Should it prove impossible to reach solid ground at a reasonable depth, the only resource is, on the one hand, to endeavor to make the available soil more dense, and, on the other hand, to broaden the base of the masonry foundation to such an extent that the pressure upon the unit of ground-surface will be reduced to the point where, without lateral displacement, it will transmit the weight of the intended structure downward. With this object in view, the excavation should be filled throughout its entire length to the depth of 3 or 6 feet—more or less, according to the nature of the soil and the weight of the intended structure—with broken stone, which must be well rammed down; or the stone packing may be made deep enough and broad enough to answer the purpose without ramming or rolling. Layers of sharp, dry sand or gravel introduced into the excavation and thoroughly rolled or rammed are well adapted for distributing an equable pressure over a large surface. If it is intended simply to build foundation-walls at the margins of the excavation, the load they will be called upon to bear may be distributed over the entire floor of the excavation by joining the walls with inverted arches. Should the access of water complicate the work, it will be possible in many cases to prevent this, while the work is in progress, by the application of one or the other of the various devices for drainage.

Subaqueous Foundations.—Work is rendered decidedly more difficult in cases where water has access to the location of the intended excavation. To get rid of it and keep the base of the foundation dry while the work of construction is going on, mechanical appliances of various kinds, such as bucket-wheels, Archimedean screws, ordinary pumps, centrifugal pumps, etc., are resorted to. It is not always practicable, however, to remove the water by these means, and in such cases it will be necessary to devise methods for sinking the foundation beneath the water.

Excluding Water: Dams.—Where the ground in which the foundation is to be sunk lies below the surface of the water, the area to be excavated must be isolated and made impenetrable to water by interposing some form of dam, the walls of which must project above the water-surface. Where the water is still and shallow, an embankment of earth—which is the simplest form of dam—may suffice; or where there is some current, bags filled with earth, to avoid the washing away of the material, may be employed. Such simple earth embankments are in use in all countries along rivers for protecting adjacent lowlands from overflow. In the United States, earth embankments (called "levees") are built up for hundreds of miles along the course of the Mississippi River.

Sheet-piling backed with an earth filling is more effective. To construct a dam of this description, gauge- or guide-piles are driven about 6 to 10 feet apart and joined by stringers. These serve to keep the piles in line while being driven. They consist of squared timbers—sometimes thinner than they are wide—cut obliquely or to an edge at the foot to allow them to be driven close together. Sometimes, also, the foot is furnished with a sharp-edged or pointed iron shoe. Figure 17*a*, *b* (*pl.* 41) shows in cross-section the form of these sheet-piles and the way in which they are fitted together. One or several rows of sheet-piling may be driven, according to the nature of the ground, their tops rising sufficiently above the water-surface to prevent danger to the excavation from overflow, and being protected on the outside by an embankment of well-packed earth. The piling surrounding the excavation may at times be required to protect the finished foundation from the undermining action of the water, in which case it will be driven with this object in view and made to serve as a permanent portion of the structure. Where the water gains admission chiefly through the floor of the excavation the difficulty may be overcome by the use of a layer of concrete, a mixture of broken stone and hydraulic cement which attains great hardness under water and becomes impermeable.

Pile Foundations: Grillage.—After the excavation is quite dry, the masonry for the foundation may be laid directly upon the ground, if the latter be firm enough for the purpose. When, however, solid bottom lies so deep that the excavation cannot be carried down to it, recourse may be had to rows of piles to bear the load of the structure and transmit the same to the solid bottom. The piles (*pl.* 41, *figs.* 15, 16) are driven at regular distances from one another, forming rows. When driven, their heads are sawed off at a uniform height, and they are then strongly bound together by two courses of stout timbers crossing at right angles (*figs.* 15*b*, 16*b*), and firmly secured to the piles and to one another by bolts or tree-nails. In most cases, partly that the load to be sustained may be transmitted to the soil surrounding the "grillage" (as the pile structure is called; *pl.* 50, *fig.* 6), and partly to prevent undermining, the spaces between the piles are filled up to the level of their heads with concrete, broken stone, etc. (*pl.*

41, *figs.* 15*a*, 16*a*). To the top of the upper course of timber is bolted a close flooring, constituting a wooden platform, on which the masonry is laid; or the upper course of the grillage timbers for this purpose may be laid as a close platform.

Further to guard against undermining, the grillage is commonly surrounded with a wall of sheet-piling (*fig.* 15*b*), or, with the same object in view, the outside row of piles is formed of close piles (*fig.* 16*b*), which are usually driven about 2½ to 4 feet apart each way from centre to centre; their diameter should be at least 9 inches. The depth to which they should be driven will depend on the nature of the soil and the weight of the structure they are intended to sustain. The entire woodwork of the grillage must be below the ascertained low-water mark, inasmuch as wood exposed to alternations of wet and dry speedily decays. Where the soil is stony or difficult to penetrate, it is usual to furnish the foot of the pile with a pointed or edged shoe of cast or wrought iron, to facilitate its descent.

Random-stone Foundations.—In cases where the access of water cannot be prevented, or can be prevented only by considerable outlay, one or the other of the following modes of laying a subaqueous foundation is employed. Where the upper strata of the bed of the river, lake, or sea are solid, a deposit of rough stone is simply thrown into the water until the surface is reached. The top is then levelled off, and the building is proceeded with above water. To insure against settlement, the larger stones are disposed around the outside of the heap. Foundations of this sort are known as "rip-rap," or "random-stone" (*pl.* 50, *fig.* 4). In the construction of docks, breakwaters, sea-walls, and similar structures, in harbors, instead of using random-stone, enormous blocks of béton are used therefor, and these are placed by divers in proper position with reference to one another.

Piles protected by Stone.—Where the solid stratum is found to be at some depth below the surface of the river-, lake-, or sea-bottom, the overlying unreliable soil must be removed by dredging before laying the concrete or stone foundation. It may also be found advantageous to employ piling under such circumstances. Figure 5 exhibits a set of piles driven into the river-bed and protected from damage by a deposit of stone. The tops of the piles are sawed off to an even height a short distance below low water, and a strong platform is erected upon them, from which the masonry is started; or the piling may be made to serve as the support of a crib of timber (floated to the proper position and sunk upon the piling by weighting with stones), and the masonry is started from a platform built upon the top of the crib. In this case the tops of the piles must be sawed off so far down that the top of the superincumbent crib shall also be below the level of low water.

Cast-iron Piles and Cylinders.—Piles of cast iron of various forms are somewhat used for sheet-piling; or, when intended to serve as bearing piles, cylinders open at both ends have been employed. These may be of considerable size, made in sections, the successive lengths being bolted together through internal flanges. (Such constructions have been described in the section on Bridges, p. 273.) Where tubes or cylinders of cast iron are employed (usually filled with concrete), they are generally carried not merely to high-water mark, but, in the case of bridge-piers, up to the superstructure proper. A modification of this method consists in surrounding a group of piles with an iron cylinder sunk to a solid bearing, after which the enclosed space is filled with concrete. In such an arrangement the piles may be carried above low water, since they are protected from decay by the enclosing cylinder and concrete filling. They are likewise protected from destruction by boring-worms. This plan was first proposed by S. B. Cushing, an American engineer, and is said to give very satisfactory results.

Wrought-iron Piles: Screw Pile.—Wrought-iron piles are also used to a considerable extent for the foundation of important structures (as, for example, light-houses exposed to the action of waves or of ice). These are shafts of rolled iron, from 5 to 8 inches in diameter, which, instead of being rammed into place, are furnished at the foot with a cast-iron screw (*pl.* 50, *fig.* 11), by which they are screwed into place by men working at long levers attached to their tops, after the fashion of capstan-bars. This system was devised by Alexander Mitchell of Belfast.

The Sand Pile for soft soils is an expedient that has grown out of the use of sand in filling foundations, trenches, etc. The mode of forming these piles is thus described by Trautwine: "A short, stout wooden pile is first driven 5 or 10 feet, or more, according to the case. It is then drawn out, and the hole is filled with wet sand well rammed. The pile is then again driven in another place, and the process repeated. The intervals may be from 1 to 3 feet in the clear. Platforms may be used on these piles, as on wooden ones. If the sand is not put in wet, it will be in danger of afterward sinking, from rain- or spring-water. In this case, as with fascines, it is well to test the foundation by means of trial loads. Some settlement must inevitably take place until all parts come to a full bearing, but it will be comparatively trifling."

Mechanical Appliances: Pile-drivers.—The simplest, and also the least effective, machines designed for driving piles, are the hand-hammers of wood or iron, weighing from twenty-five to thirty-five pounds. In another form, a hammer weighing from six hundred and fifty to thirteen hundred and fifty pounds is allowed to drop from a height upon the head of the pile. The hammer is raised between the guides of the scaffold by a rope. This passes over a pulley at the top of the frame, where it divides into a number of cords, which are drawn upon by twenty or more workmen. The hammer in this case is not lifted more than 5 feet at most. The men deliver about twenty or thirty blows, and then rest for a few moments before repeating them. In another form the hammer is not raised directly by hand, but by the intermediation of some mechanical appliance (a winch, tread-wheel, or the like). By a further improvement introduced with this form of the machine, the hammer, when raised to a certain height, is automatically released, and drops upon the head of the pile; then the hook that held the hammer follows, and seizes it again. In this form of the machine the weight of the hammer varies from eleven hundred to seventeen hundred pounds and the drop from 20 to 30 feet. Because of the greater distance of the drop, the last-described machine is much more effective than the preceding hand-machines. Aside from this, in the windlass-machines, the strength of the workmen—of whom, usually, but from four to six are employed—is applied to better advantage. Pile-drivers operated by horse-power have also been used.

Power Pile-drivers.—The modern improved forms of pile-drivers, actuated by steam-power, are much more effective than those above described. In the power-machines in common use the steam is employed to actuate a winding engine by which the pile is lifted into position and the hammer raised to the proper height after each blow has been delivered. In another form of the machine, the steam-hammer pile-driver of Nasmyth, a very heavy hammer (from three thousand to six thousand pounds in weight) is given a comparatively small drop (about 3 feet), and delivers a number of blows in quick succession. In this case the hammer is impelled by steam-pressure in addition to its own weight.

Gunpowder Pile-driver.—Excellent work has been accomplished by the gunpowder pile-driver of Thomas Shaw, an American engineer (*pl.* 50, *fig.* 8), which is from four to eight times as effective as the ordinary steam pile-drivers. In this novel machine, the hammer is operated by small cartridges of gunpowder introduced one at a time in a species of mortar, which rests on the top of the pile. The falling of the hammer explodes the cartridge, driving the pile deeply into the soil, while the recoil at the same time throws the hammer back to its first position, ready for a second blow. From thirty to forty blows per minute can readily be delivered with this machine.

To protect the heads of the piles from being shattered by the blows of the hammer, it is customary to surround them with a stout hoop of iron. This precaution, however, does not always prevent the heads from splitting, and in hard driving it is frequently found necessary to saw off the head of a pile several times before it is driven home. This contingency must be considered in deciding upon the proper length of piles for work in soils difficult of penetration. It is worthy of note that the Shaw gunpowder pile-driver does not injure the heads of the piles; in fact, the hammer never actually strikes the anvil, the cartridge being exploded, not by direct impact, but by the heat of air-compression in the recess in the top of the anvil, into which the piston of the hammer enters. The firm union of the piling may at times preferably be secured by filling in the space between them with concrete; or the heads of the piles may be permitted to project into the masonry-work of the foundation, in which case their connection by a grillage may be dispensed with.

Pile-sinking by Water-jet.—The use of the water-jet for loosening the material about the foot of the pile is frequently found exceedingly advantageous in facilitating the sinking not only of wooden piles, but also of screw-piles and of the largest cylinders. In this method, by means of a steam-pump, a jet of water is forcibly impelled through a flexible tube around the bottom of the pile. By this simple device piles may be sunk through sand, gravel, and loose soil with astonishing rapidity.

Timber Cribs.—In cases where the solid stratum cannot be reached by driving piles the timber "crib" (*pl.* 50, *fig.* 3) affords an excellent substitute. This is built of heavy squared timbers laid crosswise, notched at their intersections, so as to be bound strongly together, and enclosed at the sides with a solid wooden wall, the bottom being left open. The structure is thus divided into a number of rectangular cells. This timber framework is put together afloat at some convenient place, and, after being towed to the position destined for it, is sunk by weighting it with stone thrown into several of the cells, which have been provided with platforms to retain it. When sunk, the interstices of the crib are filled to the top with stone; or the crib may be built with only an outer row of cells for sinking it with stone, and the interior may then be filled with concrete under water. Where the bottom is irregular, a level foundation of broken stone may be prepared for the crib to rest upon, or the bottom edge of the crib may have to be shaped to conform to the inequalities, etc., so that the concrete shall not spread beyond the proper limits. When such a concrete foundation has been brought up within a few feet of the surface and properly levelled off, the masonry may be laid upon it directly. Where the structure will be exposed to scouring, the outside should be protected by sheet-piling or by a pile of heavy stones deposited around its base, as shown in the Figure.

Subaqueous Deposition of Concrete.—The usual proportions adopted for a concrete mixture are one part cement, two parts sand, and four parts broken stone. For depositing the concrete upon the river-bottom special arrangements have been contrived. Sometimes a box is employed, which, being filled with the mixture, is brought over the desired spot by means of a swinging crane, and is then lowered to the bottom, when, by pulling a rope reaching to the surface, a bolt is drawn, and, one of the sides of the box being opened, the load is discharged. The empty box is then drawn up, and these operations are repeated. Or the device known as the "tremie" is employed, which consists of a box, round or square, made of wood or of iron, of sufficient length to reach to the bottom and furnished with a hopper at the top, which projects above the water. This apparatus is first filled entirely with concrete by using some such device as the box first mentioned, and is kept filled by constantly putting into the hopper additional concrete as fast as the material passes out at the bottom. Some device of the kind here described is necessary for the purpose of depositing the concrete on the bottom, since otherwise the cement would be washed out of the mortar in falling through the water, and its solidifying power would be destroyed.

The Caisson.—Another method of laying subaqueous foundations is that of the caisson. This device is a watertight timber box whose sides are so arranged that when it has served its purpose they can be detached from the bottom, which constitutes the platform on which the masonry is built, and can be used in the construction of other caissons. The finished caisson is floated over the desired spot, and is then sunk by weighting with stones. The bottom, which forms a substantial platform for the masonry, rests either on the natural bottom of the stream (previously levelled), or on a foundation of piling prepared by sawing off the tops to a uniform height and consolidating the same by a stone or cement filling. After the masonry has been built to the desired height the side walls of the caisson are detached from the bottom and removed, while the bottom remains as a firm platform under the masonry. Figure 18*a*, *b* (*pl.* 41) exhibits a form of floating caisson used in the sinking of the foundations of the Victoria Bridge, over the St. Lawrence at Montreal.

Coffer-dams.—A modification of the method just described consists in the use of the coffer-dam. This is a strong timber crib open above and below and covered outside with closely-laid squared planks, the interstices between being well calked. The structure is strengthened by the insertion of cross-braces, to protect it against crushing by pressure when the water is pumped out of the interior. The coffer-dam is launched, floated to its destined position, and sunk to the bottom of the stream by weighting it with stone placed on a temporary platform made for the purpose. Proper measures must be taken to prevent leakage under the bottom and through the sides. Leakage under the bottom may be controlled either by a row of sheet-piling around the walls, projecting some distance above the bottom, by the introduction of a layer of concrete, or by other expedients; and leakage through the walls may be controlled by calking defective joints in the framework. The water is then pumped out of the enclosure, and the masonry, which is started on the dry concrete bed at the bottom, is carried up to the required height. Coffer-dams with exterior walls of wrought iron have been used, as at the Marne Bridge at Nogent, the Weser Bridge at Bremen, etc.

Shaft-sinking.—Another plan consists in gradually sinking to firm bottom shafts of brickwork or masonry resting on a strong curb or ring of wood or iron having a scarfed or sharpened lower edge. This is supported from a suitable scaffold, and is gradually lowered as the masonry is added until the bottom is reached (*pl.* 50, *fig.* 7). The shaft is further sunk to solid bottom by undermining from the inside by scoops, sand-pumps, etc., and thus the structure, either by the weight of the masonry above, whose walls are carried up as the shaft descends, or aided by artificial loading, gradually sinks to a firm bottom. Foundations for bridge piers have been sunk in this manner. In the case of the Parnitz Bridge at Stettin each pier was erected upon a single shaft of masonry, which was sunk dry, not by removing the earth from the open top as above described, but by using compressed air, excavating the soil beneath the foot of the curb and removing it from time to time as the sinking of the shaft progressed. In this case the curb consisted of an air-tight chamber of iron, open below, from beneath which the water was forced out by compressed air, which displaced it.

Vacuum Process.—The idea of utilizing the pressure of the atmosphere in sinking foundations originated with Dr. Lawrence H. Potts. The plan —which is adapted to soft soils only—is called the vacuum process. Dr. Potts proposed the following method of facilitating the sinking of large iron cylinders to serve as foundations of bridge piers, etc. He closes the hollow iron cylinder on top by the use of an air-tight trap-door opening upward; then, by means of a suction-pump and suitable connections, he exhausts the air from the inside of the cylinder, the same having previously been placed in proper position and pumped free from water. Under these circumstances, in suitable ground (not too compact), the atmospheric pressure will force the cylinder downward a distance greater or less according to the resistance of the bottom, and at the same time the interior will become filled with soft or semifluid earth forced into it by the atmospheric pressure transmitted through the water to the soil around the open bottom of the cylinder. The trap-door is now opened, the contents of the cylinder are removed, and the same series of operations is repeated until the bottom of the cylinder reaches a solid stratum. Additional lengths of the cylinder are bolted on from time to time as may be necessary while the sinking progresses.

Plenum Process.—In the construction of the Medway Bridge at Rochester, in 1851, it was the intention to sink the tubular cast-iron piles (7 feet in diameter) by the use of the vacuum process above described. But, as old masonry was encountered during the sinking of one of the cylinders, it became evident that the operation by rarefaction would have to be abandoned. Chief-engineer Hughes successfully applied a process that had first been made use of by the French engineer Triger in 1841 for sinking a shaft in the middle of the river Loire, and later (1850) in sinking the foundation of the Mâcon Bridge across the Saône. In the Triger system—called, in contradistinction to that above described, the plenum process—the air in the interior of the cylinder, instead of being rarefied, is compressed to such an extent as to force out the water, compelling it to escape beneath its open end into the surrounding water, leaving the interior of the cylinder dry.

At the top of the cylinder there is provided an air-lock (*pl.* 41, *fig.* 19) through which the workmen can descend to the bottom of the chamber and remove the soil from the foot of the tube by undermining. The soil thus excavated is loaded into suitable receptacles and hoisted to the air-lock. The workmen then ascend, leaving the chamber by way of the air-lock, through which, also, the load of earth is removed. Then the compressed air is permitted to escape by opening a suitable valve, and the cylinder, being no longer supported by the upward pressure of the air beneath its closed top, sinks by its own weight into the cavity or loosened soil prepared about its open bottom, while the water from without enters by the same avenue. When equilibrium is restored, the air-compressor is again started, the water is forced out, and the above-named series of operations is again repeated. As the cylinder descends, additional sections are bolted on at the top, the air-lock chambers being removed from the old, and replaced on the top of the last, section. The general method here described will be understood from Figure 19 (*pl.* 41). That the cylinder may not tilt, it is necessary to guide it in its descent by a frame of some kind resting on piles. The depth to which cylinders may be sunk by this process will be limited by the friction of the walls, and by the danger of working in a compressed atmosphere, which increases rapidly with the depth. By this process large cylinders and caissons for bridge piers have been sunk to a depth of 40 or 50 feet.

Modifications of the Plenum Process have been introduced, embodying improvements in certain details. Figure 20 shows how by a simple artifice the volume of air to be compressed is substantially diminished and the same object accomplished as though the whole interior of the cylinder were subjected to compression. In this plan a working chamber of wrought iron, provided with a roof or cover of the same material, is placed in the bottom of the cylinder. The interior of this chamber is placed in communication with the air-lock at the top by means of a metal tube of sufficient size to permit the descent and ascent of the workmen and of the buckets for removing the excavated material. By this expedient the volume of compressed-air space is greatly reduced, and the annular space between the communicating tube and the cylinder walls may be filled out with masonry or concrete as it is found necessary to assist the sinking by adding to the weight of the structure.

Plenum Process in Caissons.—The pneumatic method of founding subaqueous structures has of late years been successfully applied in the erection of several great bridges, and a number of instructive modifications have been introduced to adapt the method most advantageously to prevailing local conditions. One of these modifications worthy of mention is the plenum process in caissons in which the iron cylinders are enclosed in a pier of solid masonry starting from the roof of a caisson or rectangular box of wood or of wrought iron which rests directly on the firm stratum or rock-bed.

Foundation of the Kehl Bridge Piers.—This modification of the plenum process was first adopted in the construction of the Rhine Bridge at Kehl (*pl.* 50, *fig.* 9). To found the piers at this place by the well-known expedient of the coffer-dam would have been a very costly and tedious operation, on account of the necessity of completing the foundations to the water-line between two floods in the river, the exceedingly rapid current, and the indefinite depth of the mud, sand, and gravel constituting the bed of the river. The first proposition, to use the Triger-plenum method with iron cylinders (above described), was also deemed impracticable because of the time that would necessarily be consumed in removing the great quantity of material, before the needful depth would be reached, through the contracted area of an air-lock. To overcome these difficulties, M. Fleur St.-Denis proposed the following method with caisson:

The caisson was a wrought-iron rectangular box, 23 by 19 feet, closed at the top. The roof of the caisson was pierced with three circular openings, from which proceeded three shafts of sheet iron, the central one 5 feet and the side ones $3\frac{1}{4}$ feet in diameter. The two side tubes were each surmounted at the surface by an air-lock similar in arrangement and operation to the air-locks previously described. The arrangement of the central shaft was different. This was left open at the top and bottom; its lower end extended slightly below the lower edge of the working chamber of the caisson and dipped beneath the surface of a well into which the excavated material was dumped. A chain of dredging-buckets, operating in the central shaft, scooped the deposited material from the well in the centre, and, lifting it to the water-surface, discharged it outside. From time to time as the caisson sank these three tubes were so lengthened by the addition of sections that their tops always extended above water.

The operation was very simple. When the compressed air was forced into the side tubes and into the working chamber of the caisson with which they communicated, the water in the chamber was forced out to the level of its bottom edge; but, as the central shaft extended somewhat below this level, its open bottom dipped under the level of the water in the centre well, and, being in communication through the loose soil with the water outside of the caisson, the water rose in this shaft to the level of the river. The water was prevented from entering the working chamber by the air-pressure, which was a trifle more than sufficient to counterbalance it. The water-column in the central shaft formed a means of communication between the working chamber and the open air, the workmen throwing all the material which they excavated from the interior into the well in which the lower end of the shaft was immersed, and from which it was lifted to the surface and dumped outside by the dredges.

In the case of the Kehl Bridge several such caissons were placed side by side, so communicating as to form the support for one pier. From the outer edges of the caissons a wooden casing or box was carried up to and a little above the water-surface, where it was maintained by successive additions as the caisson settled. The interior of this casing was kept filled with béton poured in from time to time. This served not only to form the body of the pier, but also to give the caisson the necessary increment of weight to counterbalance the upward force exerted by the compressed air. When the desired depth was reached, the interior of the caisson and the interiors of the shafts were likewise filled with béton, when the foundation for the pier was complete.

Similar expedients have been adopted in other situations. The piers of the Parnitz Bridge at Stettin are founded upon cylindrical shafts, in sinking which, a round, bell-shaped working chamber was employed. Instead of filling out the interior of the working chamber and shafts with béton, a filling of sand may be employed for the same purpose.

Foundation of the East River Bridge Piers.—Another typical work executed on the pneumatic system was the founding of the piers for the great suspension bridge of 1600 feet span over the East River between New York City and Brooklyn (*pl.* 48, *fig.* 3). This was accomplished by the plenum process with caisson, as will appear from the following description, abridged from Trautwine:

The caisson at the bottom was 168 feet long and 102 feet wide (*pl.* 50, *fig.* 7). To facilitate the work, as well as to serve as a precaution against accidents, six shafts arranged in pairs were provided. Two of these were water-shafts, 7 by 6½ feet in dimensions, for removing with buckets and with hoisting-apparatus the material excavated beneath the caisson; two were air-shafts, 21 inches in diameter, through which air was forced from above, to expel the water from the working chamber, so as to allow the laborers to undermine beneath the caisson; and two were supply-shafts, 42 inches in diameter, for admitting laborers, tools, etc. The supply-shafts were furnished with air-locks on the principle of that above described. The shafts were of quarter-inch boiler-iron. The foot of the caisson was formed tapering to a sharp edge, the better to facilitate settlement, and the bottom was shod with cast iron. The wood-work of the interior of the working chamber was made fireproof by a lining of sheet-iron. From the bottom up to 14 feet the caisson was built of horizontal layers of timbers of foot-square section, the layers crossing one another at right angles, the timbers being strongly bolted together and the joints made watertight by pitching and calking. It was then launched and floated to position, and to sink it there were added fifteen courses of timbers, some one foot square laid one foot apart, the intervals between them being filled with concrete. When the caisson was sunk and the water forced out from the working chamber, the enclosed area of the river-bottom was uniformly excavated, so that the caisson should slowly descend until it reached a solid substratum. The working chamber as well as the shafts was then filled with concrete. A coffer-dam was built from the top of the caisson, and in this the masonry of the great tower was started.

Piers of the Bridge at St. Louis.—A portion of the piers of the great arch bridge over the Mississippi at St. Louis was built by the plenum process with the use of the caisson. In this instance the air-locks were not placed at the tops of the shafts above the water-surface, but were located directly over the working chambers, into which they partly projected. These air-locks were surmounted by shafts open above and communicating directly with the atmosphere. Trautwine refers to this work as affording an excellent illustration of the effective use of the sand-pump in raising sand from cylinders while being sunk in water. By means of a pump-pipe of 3½ inches area, and with a water-jet under a pressure of one hundred and fifty pounds to the square inch, twenty cubic yards of sand per hour were raised 125 feet. In founding this bridge there was attained a depth of 110 feet beneath the water-surface (*fig.* 10)—a greater depth than elsewhere had ever been reached by any similar structure.

The Air-lock.—The arrangement of the air-lock—which has several times been referred to—is shown in its simplest form in Plate 50 (*fig.* 11). Its object is to permit those employed in the work to enter and leave the working chamber, and to allow the excavated material to be lifted out of the interior, without suffering the compressed air to escape. It is a small iron chamber securely bolted upon the top of the last section of the cylinder. It is provided at the top and bottom with air-tight doors or flaps, both opening downward, or toward the cylinder.. The upper door affords communication between the air-lock and the outer air; the lower door forms the means of communication between the air-lock and the interior of the cylinder or working chamber of the caisson. A valve is placed in the top of the lock, communicating with the outer air, and a similar valve is placed in the bottom, communicating with the compressed-air workings. From the illustration it will be understood that the chamber of the air-lock may be placed in communication either with the outer air or with the compressed air of the working chamber by opening or closing the valves just described.

Operation of the Air-lock.—When a workman wishes to enter from the outside, he must first open the valve in the top of the air-lock, which permits the compressed air in the air-lock chamber to escape, whereupon the flap communicating with its interior may be opened. He thereupon enters the air-lock, closing the flap behind him, and likewise shutting off the valve in the top of the lock-chamber. He then opens the valve in the bottom of the lock, establishing communication with the compressed-air chamber. The air escapes from the working chamber into the lock; and when equilibrium between the two has been established, the door between the two falls open of itself, and the man may descend to the floor of the working chamber by the ladder. In leaving the working chamber and ascending to the outer air, these same manœuvres are performed in the reverse order. The same series of operations is required for the raising and lowering of the buckets conveying the excavated material from the workings to the outer air. In the founding of the Kehl Bridge the removal of the excavated stuff was accomplished by a continuous chain of buckets working up and down in an open central shaft (see p. 288), and a similar plan is adopted in most works where the pneumatic method is pursued.

Caisson Disease.—In pneumatic founding the effect of the compressed air upon the workmen does not appear to be notably injurious, so long as the compression does not exceed two atmospheres above atmospheric pressure, which is equivalent to a depth of about 68 feet below water-surface and to a total pressure of forty-five pounds to the square inch, or thirty pounds above the normal pressure. Beyond this the effects are liable to be dangerous, and even fatal. The younger Roebling, who finished the East River Bridge, has suffered seriously from this cause, and the medical profession has recognized a distinct type of disease, originating from exposure to compressed air, which is designated as the "caisson disease."

Excavating by the Freezing Process.—One of the most original contributions to this branch of engineering is the method lately devised by Poetsch for sinking shafts and making excavations for the foundations of buildings, bridges, and other structures, and for constructing subaqueous tunnels, bridge foundations, conduits, etc., and, generally speaking, for the execution of all kinds of excavation in quicksand and other unstable and water-bearing strata. The Poetsch system is a radical departure from all methods previously in vogue, and has the merit of great simplicity. It consists in freezing the material surrounding the space to be excavated, and in thus converting it temporarily into a solid mass or wall which permits the excavation to be made and the permanent work to be executed with the same certainty as similar work in solid ground, and with security against collapse. It dispenses with the pumping plant for keeping the workings free from water while the excavation is going on, and with the elaborate methods of holding the water back by compressed air, as in the several modifications of the plenum process above described, which involves the use of caissons, air-locks, and air-compressing machinery.

Operation of the Freezing Process.—The freezing is done by passing double pipes (one within the other) at suitable distances apart through the material to be frozen, and by causing brine—previously chilled in a reservoir by a refrigerating-machine—to circulate through these pipes. The chilled brine passes through the inner pipes and returns through the space between the inner pipes and outer pipes, the former being open at the ends and the latter closed. The heat is thus abstracted from the soil surrounding the pipes until it is frozen to the desired thickness. The returning brine flows into a tank, where it is again chilled. In Germany, by this process, several shafts have been successfully sunk through quicksand and other troublesome materials, and one in Belgium (at Houssu) has been sunk to a depth of 224 feet, all below a depth of 30 feet from the surface being quicksand which had defied every effort to accomplish the result by other methods. Figures 1, 2 (*pl.* 50) exhibit, respectively, the application of the Poetsch system to shaft excavation, and to the construction of a pneumatic caisson for the foundation of a bridge pier.

Fascines.—In other cases, where the nature of the soil is unstable or yielding to a considerable depth (as in the case of soft mud, bog, or quicksand bottom), numerous layers of fascines, or bundles of stout twigs and small branches, sunk by weighting with earth, stones, etc., are often deposited over a considerable space beyond that to be occupied by the base of the structure. The interlocking parts of these fibrous masses serve as an excellent means for distributing the pressure over a great area when the weight of the intended structure comes upon it. They not only fulfil a useful purpose in the construction of railway embankments over treacherous ground, but have also been applied with the best results to subaqueous foundation-work for bridge piers, jetties, etc. An example of this expedient applied to bridge engineering is afforded by the great suspension bridge of Kieff, in Russia (1852), with spans of 440 feet, of which the piers and abutments were founded in this manner on a shifting quicksand. "There the fascine mattresses extend 100 feet beyond the bases of the masonry which rests upon them." This expedient proved of great value in the work of improving the channel of the South Pass of the Mississippi River by the system of jetties successfully built by the late Captain James B. Eads (*pl.* 55, *figs.* 2, 3).

South Pass Jetties.—The bed of the Mississippi at the South Pass afforded an exceedingly unstable foundation of soft sediment, into which any work of stone would speedily sink and disappear; so that the task of devising a method of securely and permanently founding the masonry of these extensive lines of jetties was made extremely difficult. These jetties are simply dykes or levees under water, intended to act as artificial banks to the river to confine its waters within a narrow channel, so that the increased velocity of flow shall cause the stream to scour out for itself a channel of a required depth. It was found that piles alone or crib-work would not answer, as they were quickly undermined and washed away by the scour of the current. The plan which proved successful consisted in driving piles along the inside of the line for the intended artificial banks. Then great mattresses of willow-brush were made and securely joined together by cross-ties and pins. These were towed into position adjoining the piles and fastened to them. If placed in this manner at night, by the next morning it was found that the deposit of sediment from the current had so filled the interstices as to cause the mattresses to sink to the river-bottom. Each of these mattresses was not only fastened to others adjacent to it and to the piles, but was also anchored in place by a layer of stone. It was found that by the continued deposit of sediment in and about them they had become more solid than the natural bank. They thus serve to protect the row of piles from the current, and these, in turn, aid in holding the mattresses in place. Upon this foundation the solid stone paving of the jetties was subsequently built. This work will be more fully described in the next section.

2. River Engineering.

Source of Water-supply.—To the atmospheric precipitation of moisture in the form of rain, snow, or hail are due the existence and maintenance of the supplies of water upon the land. The larger portion of the precipitated moisture remains upon the surface, and, collecting into watercourses, constitutes the rivulets, brooks, larger streams, and rivers of their respective drainage-areas; a smaller portion sinks into the soil, and, penetrating into the crevices and cavities of the rock-strata, forms the subterranean streams, which reappear on the surface in the form of springs. The watercourses find their way ultimately to the oceans, and the series of changes here described repeats itself endlessly. The explanation of these operations lies in the fact that the air at a certain temperature is capable of taking up and retaining only a certain quantity of aqueous vapor. If a body of air charged to saturation with moisture be cooled, it will part with a portion of its vapor, which will make its appearance as masses of clouds, and under certain conditions will be condensed and fall upon the earth as rain, snow, or hail. In thickly-wooded districts, where the air is always cooler than over stretches of bare ground, the passage of a body of warm air is commonly attended with the precipitation of a part of its moisture. This explains why in such regions the rainfall is abundant and more uniformly distributed throughout the year.

Rainfall.—It is of much practical value in the study of the hydraulics of rivers to know the amount of the atmospheric precipitation in a given period of time—say in a year. This factor is determined with close approximation to accuracy by the udometer, or rain-gauge. The quantity of rainfall varies greatly, certain regions of the earth being almost rainless, while others receive enormous quantities. For any given locality, however, the annual rainfall is very constant. The amount of the annual evaporation of a given locality is measured with the atmometer. Of the total rainfall, it is estimated that about one-third sinks into the ground; the rest runs off from the impervious or thoroughly-saturated surface, and, seeking the lowest situations, collects in pools or lakes, or, feeding the watercourses, finds its way to the sea through the channels of the brooks, creeks, and rivers. Of the third that finds its way through an infinite number of avenues beneath the surface, a portion reappears in the form of springs gushing from the rocks, while another portion sinks until it reaches an impervious stratum, where it collects to form ground-water, which may rise to a considerable height by continued accumulation, and, overflowing, may contribute to the supply of the superficial watercourses.

Rivers and their Drainage-areas.—The brooks, creeks, and lesser streams by their union form the rivers, and these by their union in turn form the great river-systems. That portion of the earth's surface which contributes its rainfall to a river or river-system is termed its drainage-area or "catchment-basin." The elevated ground or ridge forming the boundaries between adjacent drainage-areas is termed the watershed, or "divide." From the area of a given drainage district and the quantity of its annual rainfall the volume of water received and discharged by the river may be determined with close approximation to accuracy. The Amazon and its tributaries drain an area of 2,000,000 square miles; the Mississippi system drains an area of 1,200,000 square miles, the Danube 269,187 square miles, the Rhine 65,280 square miles, etc. A convenient distinction is made between the upper course, the middle course, and the lower course of a river; the first has the greatest fall, and the last the least fall. The Elbe, for example, has an average fall in Bohemia of 1 in 2670; in Saxony, of 1 in 3760; and at Hamburg, 1 in 14,400 to 1 in 28,800 at ebb and flood tides respectively.

The River Defined.—The river-bed is the channel in which the water is confined and through which it is carried off; and, in respect of the bed, we may distinguish the bottom, the more or less precipitous sides, and the upper border of the latter—the water's edge. The land lying adjacent to the river-bed is called the "shore," and that area which is liable to be inundated in times of freshet is designated the territory of overflow. By the term "banks" is to be understood the limit of an area approximately parallel with the bed and cut out by the stream. The area contained between the foot of the banks and the water's edge is called the "beach;" and if this is of considerable extent, it is called the bottom-land or "lowlands."

Modification of River Channels: Erosion and Undermining.—The bed of the stream is subject to constant and manifold alterations by the action of the water flowing over it. The yielding materials of the bed and of the banks are washed away, and the more resisting materials—even the hardest rocks—are ground away by abrasion or dissolved, so that ravines and gorges are formed, some of these so colossal as to rank among the greatest of natural wonders (the great Cañon of the Colorado River, the great gorge of the Niagara River from the Falls to Queenstown, etc.). The concave portions of the river-bank are most deeply indented by the washing and undermining action of the current, while the convex portions assume more and more the characteristics of peninsulas. Then comes a flood, in which the river breaks through the projecting arm, creating for itself a new and shorter channel, and in time the abandoned channel, filling up with silt and *débris*, becomes dry land.

Transportation and Deposition of Materials.—The action of the water upon the river-bottom is such that in times of flood the coarser materials are carried farther down stream, where, with the diminishing velocity of the current, they are gradually deposited. The coarser and heavier materials (cobbles, pebbles, etc.) settle first, next the gravel and sand, and finally the fine mud or silt. A velocity of 3 inches per second at the bottom will be sufficient to tear up fine clay; 6 inches per second, fine sand; 12 inches per second, fine gravel; and 3 feet per second, stones of the size of an egg. The more rapid the current of a river, therefore, the coarser will be the composition of the materials forming the bottom of its bed. The extremely fine mud is held in suspension until the river reaches the end of its course—in a gulf or the sea—where it is deposited. One of the consequences of this deposition of sediment is the gradual elevation of the river-bed and the formation of shoals, especially in those portions where the bed becomes widened and the velocity of its current correspondingly lessened.

Deltas.—The formation of deltas at the mouths of many of the great rivers of the world is due to the causes above indicated. The river, charged with its load of fine sediment, reaching the comparatively still waters of an inland sea or gulf, has its velocity checked, and the sediment, sinking to the bottom and gradually piling up, continually extends the river into the sea. The deltas at the mouths of the Mississippi, the Nile, and the Po afford typical illustrations of these facts, and of the gradual encroachment of the rivers upon the domain of the sea.

Surface-levels and Velocity of Current.—In respect of its surface-level, three conditions of a river are conveniently distinguished—namely, high-water level, mean or normal level, and low-water level. The latter occurs usually in winter and in midsummer. High water may be anticipated toward the close of the winter and during the early spring, following upon the melting of the winter's snow. The extreme differences of level vary in different rivers: thus the Ganges, the great river of India, flows at the rate of 55,000 cubic feet per second during the dry months and 500,000 cubic feet during the four rainy months; the Rhine at Kehl flows at the rate of 13,414 cubic feet per second at low water and 165,380 cubic feet at high water; the Elbe at Dresden, 2500 cubic feet at low water and 141,000 at high water. The ratios in these cases, it will be observed, vary from 1 in 9 to 1 in 56. Large lakes exert a pronounced regulating influence upon the water-level of streams of which they are the feeders, as witness the influence of the Lake of Constance in the regulation of the upper Rhine. Floating ice may give rise to ice-jams, and, in extreme cases, to ice-gorges, where the ice-masses completely choke up the river-bed, in which case the water may be backed up to a considerable height.

Rivers Subject to Continual Changes.—The rivers, therefore, when abandoned to natural conditions, are subject to continual changes. A well-regulated stream even, if left to itself, may gradually pass beyond its controlling influences through the undermining of its banks and the deposition of sediment, whereby, on account of the rise of its bottom, the free discharge of its tributaries will be interrupted—a condition which favors the formation of marshes and swamps. The presence of sharp bends and of extreme contractions (or narrows) where the free flow of the stream will be impeded, and where ice may readily effect a lodgment and obstruct the channel, may cause inundations, which, in addition to the direct damage they may inflict, frequently cover the overflowed tracts of land with such quantities of stones, gravel, and sand as to destroy their value for farming purposes for years. On the other hand, in those sections where the channel widens considerably, the diminished velocity of the current will promote the deposition of sediment in the river-bed, and this may lessen the depth of water to such an extent as seriously to impede, or even to destroy, its navigability. Again, the natural fall of the stream is frequently so great as to render it difficult or impracticable for vessels to make headway against the current. Too many bends in the channel, likewise, are undesirable in the interests of navigation.

Necessity of Controlling the Streams.—It is the task of the hydraulic engineer to establish and maintain a regimen of the rivers, on the one hand, by the construction of *defensive* works by which their banks shall be protected against injury or destruction, and, on the other hand, by the construction of *offensive* works by which their currents shall be so controlled, deflected, or concentrated, that the tendency to shoaling, and to other irregularities which interfere with the free discharge of the water, impede navigation, and injuriously affect the banks, shall be reduced to a minimum or altogether eliminated.

Stream Measurements: Charts.—Before the plan for a regimen of the stream can be formed, the character of the stream must be ascertained, to which end certain measurements are necessary. First of all, starting with a definitive low-water level, a plan of the stream must be constructed, and this must be extended to embrace the territory of overflow. In the interests of navigation, it is of special importance to determine the trend of the bottom, or "thalweg"—the line of greatest depth. This is done by making a large number of cross-sectional measurements at proper distances apart, the lowest points of which are then marked upon the plan. The line joining these points will be the thalweg, or line of deepest channel.

Water-level Gauges.—Further, as no hydraulic work can be undertaken without proper consideration of the various levels peculiar to the stream, it is customary (in the case of all streams of any importance) to place at points convenient for observation gauges to measure the levels of the water. These are usually graduated from below upward, the graduations being made with the greatest accuracy and marked very plainly, and from these observations of the levels of the water are taken daily and duly recorded in a book kept for the purpose. The zero-point of the gauge is usually taken somewhat below the lowest water-level.

Profile Measurements.—The work of obtaining the data for mapping the longitudinal profile and the numerous cross-profiles of the stream is also of much importance. To determine the first, a line of stakes is planted, which follow the windings of the river, and these are chained and levelled. The slope of the water-surface is determined with great care. For the cross-profile, measurements of the depth at various points are necessary. These measurements are made with the measuring-rod, or, in the case of great depths, with the plummet. The cross-sections are referred, both as to position and as to direction, to the above-named line of stakes.

Velocity of Flow: Registering-instruments.—The velocity of flow of a stream will depend upon the inclination of the surface. In a portion of the stream where the cross-section for a good distance is tolerably uniform, the velocity of the current will always be uniform and may readily be measured with suitable instruments. For this purpose floats of various kinds (spheres of wood or of wax, or long rods weighted at one end to keep them in a vertical position) are placed in the current, and the time required by them to pass between two previously-fixed cross-sections is noted. Pitot's tube, which is used for this purpose, is an open tube shaped like the letter L. This is placed in the water in such a manner that the open end of the submerged leg is held facing the current, and the velocity of flow is measured by the height above the surface to which the water rises in the vertical leg. The more rapid the flow, the higher will the water rise in this. The Woltmann tachometer is a wheel-meter which may be attached to a rod and immersed in the stream to any desired depth. The rotation of the wheel is communicated by suitably-disposed gearing to an index, which registers the number of rotations, and from this the velocity of flow may readily be calculated. The registering mechanism may be thrown in or out of gear by the observer at the surface. When the velocity of flow at various points and depths of the cross-section has been observed, its mean value may be obtained by properly averaging these observations, and by multiplying the resulting mean value by the area of the cross-section the volume of water passing through the cross-section in a given time may be ascertained. The law of the relation between depth and velocity of flow is not definitely known. Instead of making direct measurements, the mean velocity of flow of a stream may be determined approximately by calculation when the fall, the mean area of cross-section, and the character of the bed of the stream are known.

Defensive Works: Fascines.—In the construction of the works required for the *régime* of a stream which take the form of embankments, training-walls, jetties, dams, levees, etc., use is made of stone, sand, and bundles of brushwood, called fascines (*pl.* 57, *fig.* 1), the latter being formed of successive superposed layers of fascine-mattresses sunk at a suitable angle, each layer being covered with stone, sand, gravel, etc., before the succeeding layer is sunk upon it. The layers of fascines are first put together floating on the surface. The weighting of a layer causes it to sink, and in so doing to turn upon a horizontal axis; and the junction which it forms with the previous layer is thus made in a manner which prevents the ballast from sliding off (*fig.* 6, right). The definitive slope of the fascine-bed is attained only after a time. The uniting of the fascines into compact masses is effected by means of plaiting the same with willow withes attached to strong stakes passing through the bundles (*figs.* 4, 5). To unite a mattress of this description with the river-bank, suitable cuts are made, into which the ends of the layers come to lie when sunk to place. The projecting portions of the mattress which are particularly exposed to the action of the current are protected with stones. The top is plaited around the edges, the spaces between being filled in with earth. To consolidate more firmly the materials, bushes are cultivated upon the crown of the construction, whose surface is commonly raised only about a foot above the water-surface, that the vegetation may thrive; or the surface may be protected by a pavement. Larger constructions of this nature may be built conveniently on the shore. These are usually formed of a number of layers of fascines, which are laid crosswise one upon another, and are secured by stakes and bound together by means of ropes or withes. These masses are floated to the desired spot, and sunk by weighting with earth, stone, etc. Figures 2 and 3 exhibit modified forms of these constructions.

Other Methods for Defensive Works.—The above-named defensive works for the protection of the banks of running streams may vary considerably according to circumstances. The planting of flat sloping sides with sod or with willows will answer only in the case of very sluggish streams. Where the slopes are steep, the points below low-water level should be protected by means of stones or fascine-mattresses. Where there is considerable current, recourse may be had to piling loose stone upon a gentle slope, which may eventually be planted with willows should the stones applied for the purpose not be heavy and large enough to answer the purpose unaided. Where an abundance of large stone is at hand, the lower portion of the slope, in the case of streams with swift current, may be protected by a deposit of loose stone, and the upper portion with a wall of masonry (*pl.* 57, *fig.* 7). It is the concave stretches of the banks that require facings of this description. Where the requirements of traffic or the value of the shore, etc., render it necessary to provide a steep slope, either sheet-piling (*figs.* 8, 9) or massive quay-walls (*fig.* 10) are resorted to.

Offensive Works.—Offensive works for stream regulation are intended either to "correct" the banks or the bed as quickly as possible, or to cause the stream itself gradually to shape its bed or its banks to the desired form. If, for example, it becomes necessary to contract the bed of a stream, so that, in consequence of the increased velocity of current, deposition of sediment at that point shall cease and a certain depth be permanently maintained, jetties are built parallel with the course of the stream, and each is connected at the upper end with the shore by a cross-dam. The height of such structures must bear a certain relation to the fall of the stream and to the velocity needed for carrying off the detritus. These structures will be covered at high water, and the suspended detritus will be deposited between them and the banks. The process of deposition will be hastened by the construction of several cross-dams and by planting the banks. If the dams are built too high, the cross-section of the stream will be too narrow at high water, and the result will be that the bed at the affected part will be scoured out too deeply, resulting, in turn, in a lowering of the level in those portions of the stream which lie above. Figure 13 exhibits a cross-section of a structure of this kind whose formation is too apparent to require description. The dams are sometimes constructed of fascine-mattresses, the side next the channel being covered with stone.

Various Systems of Offensive Works.—Where it becomes necessary to deflect the stream from the shore and cause it to deposit material for the formation of a new bank, jetties of fascines or of masonry are built out from the bank into the stream (*fig.* 11). These may be inclined up stream or down stream. The former are the more effective for the purpose, and the deposit of new material forms more quickly. On the other hand, they are more dangerous to navigation, since vessels are more liable to come into collision with their projecting ends. According to the purpose for which they are designed, the hydraulic structures of this order are distinguished by various names—thus, training-walls or embankments, designed to protect the bank; scouring jetties, designed to effect the removal of sand-bars or other obstructions, or to prevent their formation by reason of the increased velocity of currents which they cause; catch-dykes, such as have for their object to catch and arrest the sediment and cause it to be deposited in situations where it is desired to form new land; deflecting jetties, dams, or weirs, designed to intercept the stream or a part of it and deflect it in another direction; dividing jetties, often established at the confluence of two streams to guard against any irregularities that might occur at such points; finally, dams, which cut off entire branches or close up useless passes or channels. Constructions of the latter description are confined chiefly to streams of magnitude and of great importance as navigable highways.

Example of an Offensive Work.—Figure 12 (*pl.* 57) gives a view of a scheme of river-engineering exhibiting the application of the plans above described. The object sought to be accomplished is to close up the channel on the left side, and to establish and maintain a navigable channel of uniform cross-section on the right. This is accomplished in the following manner: The shore is first properly protected by embankments at *a*, and the vegetation on the island is rooted up to the line of the contemplated shore-line. Thereupon, at *b*, are built the dykes which oppose the disposition of the stream to deflect its current into the left channel. This channel is now entirely shut off by the construction of a dam at *c*, and at the same time, that navigation may not be hindered, a navigable channel, *d*, *e*, is dredged out through the sand-bank in the right channel. It is obvious that by these constructions the entire body of the stream will be thrown into the right channel, with the effect of rapidly carrying away the sand-bank by scour, owing to the increased velocity of the current. To guard against the secondary effects of this more rapid flow, the cross-dykes at *f*, *g*, *h* will be found necessary. The dotted parallel lines exhibit the new channel which the works just described will establish and maintain when their effects have been fully realized.

South Pass Jetty-works.—The Danube in Europe and the Mississippi in America have been made the subject of elaborate engineering works with the object of improving the navigability of these rivers at their mouths. The jetty-works of the South Pass of the Mississippi River constructed by the late Captain James B. Eads are shown in perspective in Figures 2 and 3 (*pl.* 55), and a brief description of them will be of interest. The object of the works was to secure and maintain a channel sufficiently wide and deep to be navigable by the largest vessels, and this required to be artificially opened through the great deposits of sediment by which the entrance to the river from the Gulf of Mexico was obstructed, rendering navigation extremely difficult, and, before the execution of the jetties, impossible, for vessels of considerable draught.

The plan of the work (which was begun in 1874, and practically finished about five years later) involved the removal of the point where the sediment of the river was originally deposited—namely, in the shallow water at the entrance of the Pass—farther out into the deeper water of the Gulf, where the filling up again of the channel would be indefinitely postponed. In accomplishing this object, the banks of the Pass were extended by the erection of artificial walls, within which the waters of the river are confined. These walls were designed to be carried sufficiently far out toward the deep waters of the Gulf, and to be so proportioned in width in relation to the quantity of discharging water as to cause an increased velocity of current, by whose aid the stream would naturally scour out for itself a channel of the required depth and width. In carrying this design into effect, two extensive lines of jetties were built along the course of the stream at the above-named situation, these jetties constituting artificial banks to the river, intended to confine its waters within a comparatively narrow channel, and to prevent them from diffusing themselves over a great area as they enter the sea. (The manner of building these artificial walls will be found described on page 292.)

The lines of the jetties are 1000 feet apart. The east jetty, from the land's end to deep water, in which the jetty-heads are built, is about 12,500 feet in length. It extends in a nearly straight line for a distance of 800 feet, and then curves to the west, in order to strike most favorably a littoral current from the east which was ascertained to exist in the Gulf. For the greater part of its length the east jetty is built on a lateral shoal having an average depth of about 6 or 7 feet; at the Gulf-end it terminates in 30 feet of water. The west jetty begins about 4000 feet lower down the river, and extends parallel to the other throughout its whole length, terminating at the same place. As collateral improvements executed in conjunction with the jetties, two auxiliary works were carried into effect. These comprise the closure of the mouth of one of the principal lateral channels (the Grand Bayou) and the building of a dyke at the head of the Pass. These had for their purpose the deflection of a large volume of water into the South Pass, with the object of causing an increased velocity of current, and consequently a greater scouring action. The effect of these engineering works has been very favorable.

Straightening Winding Streams.—Where the stream makes one or several windings or loops, its course may be straightened by cutting the channels through at the points of the curve lying nearest to each other. By this expedient a certain amount of land is gained, the necessity of constant repairs to the banks is obviated, and the course of the river is shortened. In work of this nature it is not necessary to excavate the new channel to the full section of the river-bed, but merely to dig a channel of say one-tenth to one-thirtieth its width, according to the size of the river, and down to low-water level, leaving to the river itself the task of excavating its new bed by erosion.

Correction of the Rhine.—An instructive example of the application of the foregoing principles is afforded by the engineering works by which the *régime* of the river Rhine has been established on the Bodensee-Bavarian border. The final results accomplished by these works—executed between 1819 and 1868—which embrace a correlated system of channel and shore improvements in connection with eighteen channel-cuts, will appear from the following brief statement: The river flows either in a straight course or in gentle curves between parallel banks defended by stone embankments, and with a uniform breadth of 787.2 feet. The former length of the river between Lauterberg and Worms, of ninety-three miles, is now reduced to fifty-four miles. The fall of the river—which in its former serpentine course was very irregular, so that boats going against the current required in some places but one horse, and in others five horses, for towage—is now rendered quite uniform, the surface slope being 0.4 in 1000 at Lauterberg, decreasing regularly to 0.1 in 1000 at Worms. The numerous short cuts have increased the depth of the river-bed 7.38 feet, and considerable reaches of ground that formerly were always under water are now laid dry and under cultivation. The benefit accruing from these improvement-works is further seen in the more rapid draining off of high water, and, as a consequence of the straightening of the channel, in the diminished frequency of ice-jams.

Removing Rock-obstructions in Navigable Waterways.—In certain cases where the free navigation of an important waterway is obstructed by masses of rock, it may be found expedient to remove them. To attain the desired object, it is obvious that different methods from those described in previous portions of this section must be resorted to. The operation consists, in general terms, in sinking a shaft from the surface of the rock-mass, or reef, to the depth it is intended the channel shall have, and in driving galleries in all directions from this shaft until the entire section of the reef to be removed has been honeycombed. A sufficient number of pillars are left to serve as a support for the roof of the rock, and in working the excavation the utmost care must be exercised to avoid getting too near the bed of the river, and also to avoid shattering the roof. The removal of the rock in the galleries is effected in precisely the same manner—by the use of rock-drilling machines and explosives—as in tunnelling on land. (See p. 187.) When the top of the reef lies below the surface of the water, a coffer-dam must be sunk, to exclude the water.

When the rock-section to be removed has been honeycombed throughout its entire extent, holes are drilled in the pillars and in the roof at regular distances apart; and when this work has been finished, the holes are charged with explosive material. These charges are connected with one another by conducting-wires, in order that they may all be exploded simultaneously by electrical means from the surface. When the holes are all properly charged and electrically connected, the water is permitted to enter the excavation until the entire work is flooded. The mine is then fired by the closing of an electric circuit, and the resulting explosion, if the work has been properly executed, shatters the roof and pillars to fragments. If necessary, the *débris* may be dredged up, in order to secure the required depth of channel.

Hallet's Point and Flood Rock Excavations.—The most extensive works of this description which have ever been undertaken and successfully executed were those involved in the removal of the reefs at Hallet's Point and at Flood Rock, two formidable obstacles to the free navigation of New York harbor, lying in the narrow channel leading from Long Island Sound to the East River. The removal of these reefs was undertaken by the national government, and was successfully accomplished under the direction of General John Newton of the United States Engineer Corps. Figure 1 (*pl.* 55) gives a sectional view of the appearance of the submarine excavation at Flood Rock.

Conditions for River Navigation.—As a rule, important engineering works for the improvement of rivers are undertaken in the interest of navigation. The term "navigable," as applied to a river, is a relative one. The principal conditions demanded are the following: A width of channel at least four times as great as that of the vessels intended to ply its section, and a minimum depth within this channel at least one-third greater than the draught of these vessels. Furthermore, the channel should have no very sharp curves; the current-velocity should not be too great; and if towage from the land is desired, it should be practicable to provide easy and safe tow-paths on the banks. Where the flow is rapid or irregular over considerable distances, or where the depth of water would otherwise be insufficient in dry seasons, the navigation may be improved by dividing the stream into sections or reaches, and by building across the stream at the end of each section a dam by which the water is held back. The increased depth obtained in this manner will be governed by the height of the structures. The passage of vessels is accomplished by the provision of side channels controlled by sluice-gates or locks. The constructions of this class will be more fully treated of under the head of Canals (p. 314). To pass by unfavorable reaches, it is often found necessary to build an artificial channel (canal), and to provide locks at suitable intervals to overcome the fall.

Inland Transportation: Steam-towage.—The severe competition to which inland transportation by water-routes has been subjected by the introduction and development of railways has originated a number of substantial improvements in the methods of the former. The invention of steam-towage was a decided forward step, but its application was limited principally to streams of notable magnitude and depth, while for the comparatively shallow streams, especially with those having considerable current-velocity, its serviceability was restricted. One of the chief reasons to be assigned in explanation of this is the comparative disadvantage of applying power by either a paddle-wheel or a screw-propeller to a yielding medium like water, where the absence of a fixed resistance must be compensated for by increasing the speed of rotation of the motive-power.

Chain-towage.—These facts gave birth to the idea of causing a tow-boat provided with suitable motive-power to propel itself, with its load, by traction upon a stationary chain or cable, the method being analogous in principle to the action of a locomotive drawing itself and its attached train by the tractive force exerted upon the rails by the driving-wheels. The idea has been put in practice with highly-satisfactory results. The steam tow-boat is connected with the chain by one of the following methods: Either the chain is caused to make several turns around the circumference of a drum, or of several of them, placed in the longitudinal axis of the vessel and set in rotation by the vessel's engine (*pl.* 39, *fig.* 20), or a "sproket-wheel" is employed—a wheel furnished on its periphery with pins spaced to conform to the distance apart of the links of the chain, so that the links will engage with the pins without slipping. With this device it is not necessary that the chain should embrace more than one-half the circumference of the wheel. In all cases the rotation of the drum or wheel raises the chain from the river-bottom at the bow, and as the boat drags itself forward upon it the slack is paid out over the stern, falling again to the bed of the stream. The steam tow-boats have engines of from fourteen to thirty horse-power.

Cable-towage: Clip Pulley.—Instead of chains, cables have been introduced for the same purpose. In this case the cable may be made to take several turns about the circumference of a drum or drums, to prevent slippage, or the clip pulley (*pl.* 51, *fig.* 3), which is successfully applied for haulage and hoisting in mines, may be substituted for the drum. The face of the clip pulley is set over its entire periphery with a series of movable jaws of V-shape, each leg of the V being so pivoted that when any weight is brought into the base of the V it is firmly clutched and held immovably until by the rotation of the pulley the jaws gripping the cable are one after another released. For the same tractive power it is possible to use a cable much lighter than a chain, and it has the advantage, also, of being cheaper. The irregular jerking movements caused by the winding and unwinding of the chain upon the drums, likewise, are obviated, and, finally, the cable is less liable to breakage.

Chain or Cable Towing-boats.—The hulls of these tow-boats (*pl.* 39, *fig.* 20) are built of iron. They are flat-bottomed structures shaped alike at bow and stern, with a steering apparatus at both ends. At bow and stern is a projecting arm which is free to swivel in a horizontal plane through an angle of nearly 90°, and which serves as a guide for the chain or cable. This device serves the useful purpose of allowing the course of the vessel to be altered, within certain limits, independently of the position of the chain, so that passing vessels may turn out for one another. This device likewise assists in the task of keeping the chain in mid-channel. It is found to have a tendency in curved sections of the channel to work over toward the convex bank; in consequence of which, after the passage of a number of tows, it will be found to have become slack. To remedy this, the towing-vessel is caused to pass alone from time to time without a tow, and by the forcible aid of its rudder the return of the chain to mid-channel is accomplished. The chain used for steam-towage on the Elbe is formed of round iron links having a diameter of .86 inch, and a weight of twenty-two and a half pounds per running yard.

From the data obtained in practice on the Upper Elbe, it is found that a chain towing-boat will draw a load of fifty thousand hundredweight (about twenty-five hundred tons) at the rate of two and a half to three miles per hour. The chain-boat requires less power than the tug, and consumes, consequently, less fuel. The number of the crew may be reduced, the towed vessels can dispense entirely with the use of masts and tackle, and the forwarding of freight is done more rapidly and with greater regularity and certainty as regards time of delivery.

Employment of Towage Systems.—The earliest experiments with steam-towage date from the year 1820. Chain-towage, in its present perfected state, dates, however, from the year 1853, when it was first introduced upon the river Seine. In Germany the first chain was laid in the Elbe between Neustadt-Magdeburg and Buckau. The system has since been greatly extended on the Elbe, and has been applied to large sections of the Rhine, the Danube, the Oder, the Brahe, and other German streams. In France steam-towage has been applied in the Seine and the Rhone, and in numerous canals. In Belgium and Holland it has been extensively introduced, cables as well as chains being employed both in rivers and in canals. In other European countries less has been accomplished in this direction. In America chain- (or cable-) towing as above described does not appear to have received the attention it deserves. Towing by free self-propelling steam-tugs of special construction to reduce the danger of the washing away of the banks is in use upon the Erie Canal.

3. Embankments and Drains.

Dykes.—To prevent the incursions of the sea as well as of streams, structures called "dykes" or "embankments" are built. The height to which such works must be carried will depend upon the object they are designed to serve. Dykes that are to protect the adjacent lands from inundation by the highest flood-waters of spring must be carried up to a considerable height, as compared with those intended simply as a protection against ordinary high waters. The latter are employed to permit the overflow of the adjacent lands during the season of the spring floods, that they may be benefited by the deposition of a layer of the fertilizing river-mud. By providing the high dykes with suitable irrigating drains and sluices, through which the water may be delivered when and in such quantity as it may be required, the same object may be accomplished. The principal embankment may, as occasion requires, be reinforced by others farther back, which will serve to confine the inundated tract within narrower limits should the main embankment be broken through.

Defects of the System.—While the land adjacent to and outside of the embankments retains its original level, the level of the beach which is subject to overflow and the river-bed proper are constantly rising, owing to the deposition of sediment. As the water-surface must necessarily rise correspondingly, it is evident that the embankments will in time cease to afford adequate protection. The obvious remedy is to build the embankments higher, but this is attended with danger of disastrous inundations should the walls be breached at any point. For some seven hundred miles along its course the Mississippi River is prevented from overflowing the adjacent lowlands by a line of embankments called "levees." (See p. 292.) A large portion of Holland is similarly protected, as is likewise the valley of the Po. In some cases the elevation of the embankments in consequence of the constant rise of the river-bed from the deposition of sediment has been carried to such an extreme that the bottom of the river-bed lies many feet above the level of the surrounding plain.

Construction of Embankments.—The crown of the embankment should be at least 2 feet above the highest water-level. The breadth of the crown should be at least 3 feet; and if it is intended to serve as a roadway, it should be considerably broader. The inner face (that on the stream-side) should have a gentle slope, to enable it better to withstand the force of the current. Ramps are arranged at intervals upon the inner slope, so that wagons may easily reach the roadway on the crown of the structure.

Stability of Embankments.—To insure the stability of embankments demands constant vigilance. Should any symptom of weakness appear or a slight leak be detected, it must receive immediate attention, or a breach may be made through which the water would rush, destroying a portion of the embankment and causing a destructive inundation. Such disasters have occurred repeatedly in various parts of the world where this system of defensive works is in use. Notable instances are the repeated inundations of the valley of the river Po, the flooding of the valley of the Theiss, by which the town of Szegedin and a vast tract of surrounding country have suffered extensive devastations, and the constantly-recurring inundations of the lowlands of the Mississippi Valley, by which thousands of square miles of cultivated lands and numerous towns and cities are annually subjected to great damage.

Tributary Streams: Drains.—That the embankments built along the course of a river shall serve effectively their intended purpose of protecting the adjacent lowlands from inundation, it is manifest that the banks of its tributary streams must also be similarly guarded as far back from their points of confluence as the influence of the flood-water of the main stream is likely to be felt. The banks of small confluents are at times lined with masonry, and the stream is led into the main one by means of a covered drain of masonry built through the embankment. To control such outlets and to prevent the flooding of the land behind the embankment by the high water of the main stream, they are provided with sluice-gates or self-acting valves or doors. The flood-waters, as a rule, run off rapidly, so that the penned-up tributaries, which during this period are liable to overflow their banks, will soon resume their free discharge through the sluices. To drain at low water the lowlands adjacent to the stream, the drainage-sluices may be pierced through the main embankment, their outlets being provided with some convenient form of gate or door, so that it may be opened or closed, as may be found necessary.

4. DAMS AND SLUICES.

Uses of Dams.—A dam is a solid bank or barrier built across a stream to raise the level of the water. Structures of this character are designed for various purposes; as, for example, where it is desired to utilize the water for irrigation, or where it is desired to conduct the water through a side channel in order to apply the greater head thus obtained to the driving of water-wheels, turbines, etc., or, finally, where it is necessary to raise the surface of the water in rivers in order to obtain a sufficient depth for navigation. Where dams are erected to obtain a greater depth of channel for purposes of navigation, suitable means must be provided for permitting the passage of vessels from one reach to another. For this purpose there are provided, in suitable side channels, locks, whose construction and operation are described under Canals. It is manifest that the height of structures of this kind should be no greater than is just necessary to accomplish the object of their establishment—not solely on account of the needless expenditure involved, but principally because the adjacent lands may be exposed to serious danger in periods of extreme high water.

Classes of Dams.—To this order belong the high masonry structures that are occasionally built across the narrow gorges of deep valleys to act as storage-reservoirs for retaining the flood-waters of rivers, which may be utilized for purposes of irrigation, for the water-supply of towns and cities, or incidentally to prevent destructive inundations. Again, the structure may be so low that it will be covered even at low water; it is then called a "drowned dam." Dams of this kind have a very restricted application in special cases of river-improvement. The height of the dam commonly in use lies between extreme high-water level and extreme low-water level. At low water its top is dry, but as the water-level rises it is overflowed. The structures of this class—called "overfall dams"—rank among the most important of those which fall in this category, and of late years their construction has been substantially improved. Although in providing for the rapid discharge of the flood-water these modifications are much superior to the simple overfall dam, they are inferior to the more modern structures called "movable dams," which may be lowered or removed either in part or wholly, and so allow the flood-water free exit. (See p. 309.)

Oblique and Curved Dams.—Dams are usually built at right angles to the shore—a disposition which not only reduces the cost of construction to a minimum, but also does away with the formation of currents and eddies by the overflow, which may endanger the bank, as may be observed in the case of dams built obliquely across the stream on the side toward which they are inclined. Dams curved up stream are still better in this respect, as they direct the overflow away from the banks, but they cost more to build. Where a passage-way for vessels is provided, the dam not infrequently is given an irregular form in order to direct the stream away from the channel and thus render the passage of the vessel easier. At the same time, it should be observed that the oblique dam, having an increased length of sill, presents a correspondingly greater surface for discharge, and consequently that the volume of the overflow for any given height of the water will be greater. The oblique dam will, therefore, to a certain extent prevent the damming of the flood-waters.

Masonry Dams.—The fixed or solid dams are constructed of various materials. Those built of stone are the most permanent, and are therefore to be preferred. In practice, two profiles for these structures are in vogue: either they may be given a trapezoidal cross-section when the overflow falls over them perpendicularly, or they may be given on the discharging side a gentle curvature sloping down to the river-bed (*pl.* 57, *fig.* 14). The first-named and simpler construction is adopted where the river-bottom is rocky and cannot be disturbed by the impact of the falling water. Where the bottom, however, does not possess the solidity necessary to resist disintegration by the overfall water, it must be protected in some manner along the foot of the dam as far as the action of the falling water is felt (for example, by a bed of concrete held between sheet-piling, etc.). Where the dam has a curved profile, the overflow should be conducted as uniformly as practicable, and without eddies, into the river-bed. To this end the protected surface below should be made broad enough to insure that the breaking up of the eddies formed by the mingling of the rapidly-flowing water from the dam with the slowly-flowing water of the lower section shall take place over the protected surface, and thus avoid the washing out of the river-bottom.

Founding Masonry Dams.—The mode of founding the dam-body will depend on the character of the river-bottom. In Figures 14 and 15 the dam is founded upon piles, the spaces between the tops of which are filled in with masonry, forming a solid platform. The utmost care must be bestowed upon the finish of the exterior covering of the masonry of the dam, for, should a single stone become dislodged, the injury done by the impact of the water upon the exposed part is generally greatly increased. Abutments, usually of masonry, unite the end of the dam with the banks. They should be high enough and carried far enough inland to prevent flood-water from overtopping them or finding its way around their extremities, as else the structure will be liable to undermining and destruction.

Timber Dams.—In timber dams, the front or face may be either vertical or sloping, as above described. The body of such structures is formed of one or several walls of sheet-piling built across the stream and supported by lines of piles. The structure is made watertight by filling in the space between the walls of sheet-piling with earth or gravel. The whole is then covered with a platform of planks, which forms the surface of the dam. In the rear a backing of gravel, gravelly earth, or stone is disposed sloping gradually down to the stream-bed. As in the case of the above-described masonry dams, the ends of the dam must be connected with the shore in the most substantial manner, to avoid the danger of undermining. In building works of this kind, either the stream may be temporarily turned from its course while the work is being carried on or the structure may be erected in sections, the working ground of each being protected from the entrance of the water by an enclosing coffer-dam, as in the case of bridge-pier foundations; or other expedients well known to engineers (see p. 297) may be resorted to, as the circumstances of each case may indicate.

Timber Dams in the United States.—The practice in the construction of timber dams in the United States is sufficiently interesting to warrant some attention to the subject. The following data are condensed from Trautwine (*pl.* 56, *figs.* 1–8): "In the United States they (wooden dams) are usually of crib-work, of either rough round logs with the bark on, or of hewn timber—in either case, about a foot through. These timbers are merely laid on top of each other, forming in plan a series of rectangles with sides of about 7 to 12 feet. They are not notched together, but are simply bolted by one-inch square bolts (often ragged or jagged), about 2 to 2½ feet long, through two timbers at every intersection. These are not found to rust or wear seriously, even when exposed to a current. . . . . Round logs are flattened where they lie upon each other. Experience shows that firmer but more expensive connections are unnecessary. The cribs are usually, but not always, filled with rough stone. In triangular dams, disposed as in Figures 1 to 3 (*pl.* 56), this stone filling is not so essential as in other forms, because the weight of the water and of the gravel backing tends to hold the dam down on its base. Still, even in these, when the lower timbers are not bolted to a rock-bottom or otherwise secured in place, some stone may be necessary to prevent the timbers from floating away while the work is unfinished and the gravel not yet deposited behind it. On rock the lowest timbers are often bolted to it, to prevent them from floating away during construction; and when the water is some feet deep, this requires coffer-dams. Or the cribs may be built at first only a few feet high, then floated into place, and sunk by loading them with stone, for the reception of which a rough platform or flooring will be required in the cribs a little above their lowest timbers. . . . . The water may flow through the open crib-work as the building higher goes on, attention being paid to adding stone enough to prevent it floating away if a freshet should happen. Or cribs shown in plan in Figure 4, loaded with stones, may be sunk, leaving one or more intervals between them for the free escape of the water, and these openings may be finally closed by floating into them closing-cribs like Figure 4*n*.

"The workmanship of a dam in deep water can, of course, be much better executed in coffer-dams than by merely sinking cribs. The joints can be made tighter, the stone filling better packed, the sheet-piling more closely fitted, etc.

"When a very uneven rock-bottom in deep water, or the introduction of sluices in the dam, or any other consideration, makes it expedient to build dams within coffer-dams, both should be carried on *in sections*, so as to leave parts of the channel-way open for the escape of the water. Commencing at one or both shores, the first section of the coffer-dam may reach say quarter-way or more across the stream. In the section of the dam itself built within this enclosing coffer-dam, ample sluices should be left for the water to flow through when we come to build the *closing* section of the coffer-dam. When the dam has been finished, these sluices may be closed by drop-timbers (timbers ready prepared for closing an opening through which water is flowing, and suddenly dropped into place by means of grooves or guides of some kind for retaining them in position). Before removing one section of the coffer-dam, the outer end of the enclosed dam itself must be firmly finished in such a manner as to constitute a part of the inner end of the next section of coffer-dam. . . . . In some cases of shallow water mere mounds of earth may answer for coffer-dams, or rough stone mounds backed with earth or gravel."

The illustrations (*pl.* 56) shown in connection with what has preceded, according to the same authority, are "sections drawn to a scale of existing dams in Pennsylvania that have stood successfully the force of heavy freshets for a long series of years." Thus, Figure 1 is a dam on the Schuylkill Navigation; Figure 2 is a canal-feeder dam on the Juniata; Figure 6 is also on the Schuylkill Navigation; Figure 8 exhibits the form used on the Monongahela Slack-water Navigation. A usual precaution to protect the front of the dam against the impact of the overfall water in time of freshet is an apron of round logs or planks like that shown in Figures 2 and 5. A modification of this is seen in Figure 7, which shows a very effectual mode of breaking the force of the falling water in the case of a soft bottom by building the front of the dam in the form of a series of steps, with an apron extending out for some distance below.

Movable Dams.—As the solid dams fulfil their intended office only when the stream is at normal or low-water level, and are rather objectionable than otherwise during periods of high water by reason of the impediment which they form to the free discharge of the stream—a defect which even the addition of draw-doors does not fully remedy—movable dams have been devised. These are structures which, at high water, may be in part or wholly lowered. In the former case the dam consists of a submerged fixed portion and an upper removable part, resting upon it and extending up to the crest of the dam. In the latter case the entire structure admits of being lowered to the river-bed or removed, leaving the channel unobstructed. The constructions of this order are distinguished from the above-described sluice-dams (which, strictly speaking, are also movable dams) in requiring less power and less time for their operation.

Frame- or Needle-dams.—The so-called "frame-" or "needle-dam" (*pl.* 57, *figs.* 16, 17) is a form of the movable dam that has come into general use. It consists, substantially, of a series of iron frames arranged parallel with the channel, by which frames the solid barrier constituting the dam is supported. This barrier is formed of a series of wooden stakes of proper length standing approximately vertical. At their lower ends they bear against a sill, and at their upper ends they rest against a horizontal bar, which, in turn, connects with the iron frames. The frames also support a foot-bridge, from which the work of raising or lowering the dam is effected. To lower the dam, the wooden stakes (or "needles," as they are termed) between two contiguous frames (beginning at the end-frames) are raised from the foot-bridge; one of the end-frames is then freed by removing the horizontal bar connecting them; the section of the bridge is taken up and the frame, which is hinged at the bottom, is lowered on to the apron of the dam, by means of chains. In the same manner each succeeding frame is disconnected and lowered to the bottom, until, when the last is reached, the channel is left free from obstruction. In some cases the needles are not raised up singly, as above described, but are freed in groups by successively withdrawing the connecting-bars against which their upper ends rest. By this means all the needles between two adjoining frames are simultaneously freed. The re-erection of the structure is accomplished by reversing these operations.

Modifications of the Needle-dam.—In a modification of the needle-dam, the barrier closing the space between two adjacent frames is formed by a wooden hinged shutter, which is rolled up from the bottom when it becomes necessary to open the dam. In another, more elaborate, and expensive construction the vertical iron frames are suspended from an overhead girder which rests on piers of masonry. In this construction the frames are raised entirely out of the water into a horizontal position when the dam is to be opened. The apertures between the frames, when lowered, are closed by means of hinged shutters. In other modifications of the frame-dam, sliding panels have been employed for the same purpose.

In the system devised by Thénard the upper or movable part of the dam is formed of gates or shutters which are hinged at the bottom. They are supported in the vertical position against the force of the current by means of iron props; and when these are removed, they fall to the bottom. In this modification it is necessary to provide a second, up-stream gate, to relieve the main dam from the pressure of the current in order to raise the latter into position after lowering. A number of modifications of this form also exist in which the use of up-stream shutters is dispensed with. Figure 9 (*pl.* 56) exhibits a form of movable frame adopted by the United States government engineers, and used in the construction of the Ohio River improvement at Davis Island. In another form the dam is self-acting, the shutters being attached in such a manner, in a position inclined to the current, to a horizontal axis upon which they may turn, that they will be lowered by the weight of the water above them when this reaches a certain predetermined height for which they have been adjusted.

The Drum-dam, which has been introduced in France, is formed of an upper and a lower iron paddle, so devised as to be capable of a quarter revolution about a horizontal axis. The upper paddle constitutes the dam, and by suitably admitting water through sluices into the drum in which the lower paddle is enclosed, so that it shall act upon the upper or lower side of the under paddle as may be desired, the upper paddle, forming the dam, will be raised or lowered accordingly.

Draw-doors or Sluice-gates.—Inasmuch as the discharging capacity of the stream is materially reduced by the erection of a solid barrier, there will be a disposition to deposit sediment in the lower part of the reach near the location of the dam, owing to the reduced velocity of the current. This action, in turn, by raising the bed of the stream, will gradually enlarge the area of the inundated tract behind the dam. To obviate these objectionable features, openings are sometimes provided through a portion of the dam, reaching to the bottom of the river-bed and furnished with draw-doors (sluice-gates) or other devices by which they may be closed at pleasure. These gates or doors are kept closed during periods of low water, but are raised in flood seasons. The arrangement thus provides for the more rapid discharge of the water at high-water stages of the stream and neutralizes the tendency to the deposition of sediment, with its attendant objectionable features. Such structures are called "draw-door" or "overfall dams" (*pl.* 57, *figs.* 14, 15). To provide for the prompt discharge of the water if the rise of the stream is very considerable, it may be necessary to increase the number of these openings until their united areas approximate to that of the cross-section of the stream (*figs.* 18, 19).

Operating-mechanism of Draw-doors.—These draw-doors may be so arranged as to slide vertically in grooved guides formed at the sides of vertical frames or piles. By closing these doors the water behind the dam is retained; by partly or entirely raising them the discharge may be controlled at pleasure. In important structures of this kind the draw-doors and the frames in which they slide are constructed of iron, and to reduce the friction—which, in the case of large doors worked against a strong head of water, is considerable—the doors are sometimes made to slide over rollers disposed in the sides of the frames. The frames may be firmly secured in position by fastening their upper ends to a stout horizontal beam of timber, or by employing some other convenient mode of bracing. Entirely across the dam extends a foot-bridge, which carries the appliances by which the doors are raised or lowered. These may vary greatly. In one form the door is suspended from a horizontal axle or drum, and is raised and lowered by a lever or crank attached to the same (*fig.* 18); in other cases the object is accomplished by suitably-disposed gearing, etc. Whatever be the method adopted, however, the hoisting-mechanism must be powerful enough readily to permit the operation of the doors against the pressure of the highest flood-waters with the force of attendants on duty. To reduce the power required, as well as to avoid the use of complicated mechanism, it is customary, in the case of heavy doors, to form them of sections, which lie one over the other, and which are raised or lowered successively (*fig.* 19). In place of the draw-door, other devices have been suggested and applied to accomplish the same purpose; these, however, it will be unnecessary to describe.

Side-channels and Locks.—The combination of the overfall dam with sluices (*figs.* 14, 15) serves, as above explained, to lessen the damming back of the water during floods by providing means for its more rapid discharge than by overflow alone, and likewise to render navigation as well as rafting practicable in streams affected by a very variable water-level. The dam-openings for the passage of vessels are usually made in the form of locks (*pl.* 52, *fig.* 3), which mainly consist of an enclosure forming a side-channel connecting the upper and lower reaches of the stream; this channel, which is provided at both ends with gates, is of sufficient length to receive the largest vessel required to be passed. By properly opening and closing these gates the water-level in the lock may be raised to that of the upper reach or lowered to that of the lower reach. The passage of vessels from the upper level of the dam to the lower level below it, and *vice versa*, is thus rendered easy. (See Canals.) As the locks require to be protected against the entrance of flood-water, it is customary, where it may be found necessary, to provide the dam with a number of draw-doors, through which the water may be freely discharged should it rise high enough to threaten the invasion of the lock.

5. CANALS.

Navigable canals are artificial water-ways. They are distinguished from the natural water-ways by having a very slight fall, in consequence of which the water has only a scarcely-perceptible current; so that boats require to be propelled by some means in both directions, while in natural waters they require propulsion only in going up stream. Nevertheless, navigation by canals is decidedly more advantageous than by natural water-ways, for the reasons that it affords great safety, that the water-level is practically uniform at all times, and that rope-towage presents great conveniences. Furthermore, the course of the canals is much less winding than that of most rivers. Canals follow the elevations and depressions of the country through which they pass, being divided into a number of sections, or reaches, placed at different levels, the successive sections being connected with one another by means of locks. Canals may be built either to connect two rivers (or other bodies of water), or to afford a passage around dangerous places in otherwise navigable streams, or to shorten winding or irregular portions of their courses, or, finally, to confer the benefits of water-transportation upon regions naturally destitute of navigable water-ways.

Advantages of Canals.—Compared with transportation by roads, canal transportation presents decided advantages, as will become apparent from the statement that, while a horse is capable of drawing twenty hundredweight over a good road and about two hundred hundredweight on a level tramway, he can draw fifteen hundred hundredweight upon a broad canal. Many countries—Holland, for example—owe much of their commercial and industrial development to the admirable facilities for inland traffic which their systems of canals afford. Canal traffic, however, has lost much of its importance since the introduction of the railway, by which the demands of commerce for the rapid and regular despatch of commodities are more satisfactorily met than by the canals, whose slower operations are liable to interruption in times of drought, and, in more northerly countries, by the winter's ice. In many countries, from this latter cause, canals are available for traffic during only six or eight months of the year. Their advantages, however, will appear most favorably where they constitute a series of connected waterways, and their construction is justified where they effect a notable saving in the time of passage between important points, or where they are made to connect large waterways and afford an outlet for the crude agricultural and mineral products of thinly-populated districts. The development of the railway, however, has reduced the system of canal transportation to a subordinate rank, and the day for planning and constructing large and independent canal systems has passed.

Canal-towage.—On a number of the more important European canals the transportation of freight requiring a prompt delivery is done by means of canal-boats propelled by steam; but these consume considerable time in the passage of the locks, and often occasion serious damage to the banks by the washing action of the waves they cause. In certain situations steam towing-vessels have been introduced, though with questionable advantage. A substantial improvement in canal transportation was effected by the introduction of the system of chain- or cable-towage, which has been sufficiently treated of in what has preceded. (See pp. 302, 303.)

Locating a Canal.—The preliminary work required in locating the line of a canal is substantially the same as that required in laying out a railway route. The width of the canal must be sufficient to permit two boats easily to pass each other, and its depth should be about one foot deeper than the draught of the heaviest-laden boats it is intended to serve. Where the canal intercepts the course of a brook which cannot be diverted into another channel, the brook is carried beneath the canal through a culvert of masonry or through iron pipes. Deep valleys are crossed by aqueducts, which are distinguished from viaducts only in that the highway will require to be impervious to water and to be given a special form adapted to its intended service. Where rising land is met, it is possible that a point may be reached where it will be found more advantageous to carry the canal through an underground channel than in a deep open cut. Figure 2 (*pl.* 52) exhibits a canal tunnel of this description. Such expedients, however, are objectionable, on account of the difficulties of passage, and are therefore resorted to only where they cannot be avoided.

Water-supply.—Although there is no flow of water in the channels of canals, yet, owing partly to evaporation and percolation and partly to leakage through the locks and the loss of a certain volume of water at each passage of a boat, there will be a constant waste that must be replenished from some source of supply. Canals that are not built along the course of a river or that do not open into a river at their highest level must receive a supply from small streams along their course. In case a constant and sufficient supply cannot be obtained from such sources, it will be necessary to construct large storage-reservoirs for the purpose. To this end, a deep and narrow valley or gorge is selected, in which the water is impounded by building across its course a dam of masonry or earth. For conveying the water from the reservoir to the canal cast-iron pipes are used; these pass through the body of the dam, and are opened or closed by means of common gate-valves. To permit the repairing of the pipes, it is necessary to provide them at the in-take with an additional hinge valve (*fig.* 6), which in case of necessity may be closed by suitably operating the lever, to which a chain is attached for the purpose.

Surplus Water.—For the discharge of surplus water which may enter the canal during floods, and may overflow the tow-path and cause breaches in the banks, waste-weirs must be provided. The number and location of these will be governed by circumstances. They should be located at the top water-level of the canal, and at suitable intervals along its course where dangerous accessions of flood-water may be apprehended. The syphon sluice (*pl.* 52, *fig.* 7) is a self-acting device which discharges the surplus water when it reaches a certain height. Another form of self-regulating waste-weir (*fig.* 8) is operated by a float which rests on the surface of the overflowing water, and is connected by levers with the draw-door of the weir.

Loss of Water.—A certain quantity of water, corresponding to the volume required for filling the lock-chamber, is used in effecting the passage of each vessel through the lock. In dry seasons the amount of water at command is occasionally insufficient to provide for the needs of canal traffic. Various plans have, therefore, been devised for reducing the large quantity of water that may be required for locking. Near the locks are arranged basins which receive the water flowing out of the former when they are emptied, and return it when they are to be filled. The same object is accomplished by building two locks side by side, one serving as the basin for the other. On the Great Western Canal, connecting the Thames and the Severn, to overcome a lift of 44.6 feet are employed movable wooden chambers which can be made to counterbalance one another, and may thus be raised to the upper level or sunk to the lower, carrying the vessels with them. (See p. 320.)

Locks (*fig.* 3) are side-channels which are separated from the body of the stream by solid walls and bottom, and whose ends are formed of movable parts (gates) which may be opened or closed, as may be required; they afford a means whereby a vessel may be transferred from a higher to a lower level, or *vice versa*, the vessel being floated into the chamber of the lock, where it remains while the water therein is either raised or lowered. Locks are usually built of sufficient size for a single boat only, but are occasionally built large enough to accommodate several at a time (double locks). In this case, that the boat entering the lock first may also pass out first, the ends of the structure are not placed opposite to each other, but at a suitable angle.

The floor of the tail-end of the lock (tail-bay) is on a level with the bottom of the lock-chamber, the two together forming the lower floor, while that at the head lies as much higher as the fall of the lock, and is called the upper floor, or head-bay. The difference in elevation between the bottom of the lock and the top of the head-bay is called the "lift." The bottom between the two portions is steeply inclined. At each end of the lock is the gate-chamber—that is, the space within which the two wings of the gate move in opening and closing. On each side of this chamber suitable recesses are provided for the reception of the leaves of the gate, so that when opened they may lie flush with the side (wing) walls of the lock. That portion of the recess just named in which the gate-post (quoin) turns is called the "hollow quoin." When closed, the gates rest against a bottom sill, and are pressed by the water of the upper level so firmly against the sill, the hollow quoins, and each other that the lock is thus rendered practically water-tight.

Sluices.—To admit the water above into the lock, and thus raise the vessel or vessels in them to the upper level, or to let out the water from the filled-up lock, and thus sink the vessel to the lower level of the canal, either sluices formed in the gates are used (*pl.* 52, *fig.* 3) or the water is admitted through suitable channels provided in the side wall of the lock, the opening or closing of said channels being controlled by a valve.

Flood-gates.—The tail-end of the lock, which connects a navigable canal with the stream, must obviously be so arranged as to protect the lock-chamber from the entrance of the highest flood-water. This portion of the lock is therefore provided with a supplementary set of gates, called "flood-gates," that open out toward the stream. In the case of tide-locks at the entrance of ship-canals, it is customary to provide the upper gates with additional sections, one above the other, so that the height of the upper gates, when necessity requires, may be raised sufficiently to protect the lock against an unusual high tide.

Construction of Lock-chamber.—The lock-chamber comprises two parts—the walls and the bottom. They are built either of stone or of timber; more rarely, of cast iron. Timber walls for this purpose are subject to leakage, and require frequent repairs. Masonry walls are best made of hewn stone laid in hydraulic cement. The bottom is formed generally of a stout timber platform extending out beyond the walls. This foundation is usually a grillage (*pl.* 50, *fig.* 6)—that is, several courses of stout timbers laid crosswise and securely bolted or tree-nailed to the tops of a set of wooden piles sawed off to a uniform height. Upon the upper course of this grillage a close platform of timber is bolted, and the joints are calked as additional security against leakage. It is customary to excavate the soil around the piles to the depth of several feet, and to fill this space up to the level of the under surface of the platform with well-rammed gravel, stone spawls, etc. The bottom is sometimes constructed of masonry, and in situations where an upward pressure is to be feared it is built with reverse arches—that is, arches having their concave faces directed upward.

Construction of Head-bay Walls.—The walls and bottom of the heads of the lock are formed either of timber or of stone. As these parts are required to resist the pressure of the upper-level water, special care must be taken to secure solidity and to prevent leakage through the sides or the bottom, by which the surrounding earth would be washed away, thus endangering the structure. To accomplish this, the walls are defended by sheet-piling (*pl.* 41, *fig.* 17), by which they are enclosed, and which is carried below the bottom; the greatest care is bestowed upon the construction. Locks have also been built entirely of concrete (for example, the lock at the embouchure of the Franz-Joseph Canal into the Danube). Some of the locks on the Ellesmere Canal near Beeston Castle, England, have their walls and floors of cast-iron plates.

Construction of Lock-gates.—The construction of timber lock-gates is shown on Plate 52 (*fig.* 3). For the attachment of the leaves of the gates, the lower end of the turn-post is furnished with a pin that is let into and turns upon a socket provided for the purpose, while the upper part of the post is held by an iron collar firmly anchored into the masonry. It is found preferable to form the socket in the lower end of the turn-post and to attach the pin to the bottom of the chamber, for with this arrangement sand is not likely to work its way into the socket. The gates, that they may not sag, are strongly braced, as shown in the Figure. To lessen their weight, large gates are furnished on their lower face with rollers or are made hollow. Of late, cast- and wrought-iron gates have been introduced with much success.

To prevent the entrance of water to the lock-chamber while the gates are being repaired, grooves are provided in the so-called "head-bays" and "tail-bays" for the insertion of watertight bulkheads of beams before and behind the gates respectively. In the case of small and comparatively narrow locks, the gates may be made of a single piece.

Operation of Locks.—The operation of locking a vessel is substantially as follows: If a vessel is going up stream, the lower gates are opened, the vessel passes into the lock, the lower gates are then closed, and the water from the upper level is admitted to the lock through the sluices in the upper gates or through the side-channels above described until the water-level in the lock is the same as that of the upper level. The upper gates are then opened, and the vessel passes out. When the vessel is passing down stream, these operations are reversed. The depth of the lock will vary from 6 to 25 feet, according to the nature of the canal and the kind of traffic for which it is designed.

The Suez Canal is thus far the most important ever completed. The canalization of the Isthmus of Suez had been attempted as early as the fourteenth century B. C., though it appears that the plan then was to form a connecting waterway between the Red Sea and the Nile. This project was afterward successfully carried out, and the canal in question is known to have been in existence until about the eighth century of the Christian era. The first Napoleon projected the connecting of the Mediterranean and the Red Sea, but, having been misled by defective preliminary surveys, he abandoned the enterprise. To De Lesseps is due the honor of having revived the project, and of having successfully completed the most important engineering work of modern times—not, perhaps, so much in respect of the difficulties to be surmounted, which were not of a very formidable character, as in respect of the results that have followed the opening of the new highway.

The whole length of the navigation is eighty-eight geographical miles, of which sixty-six miles are actual canal made by cuttings, fourteen miles are made by dredging through lakes, and eight miles are formed of natural waterway. The width of the canal channel at the bottom is 72 feet, and the depth 26 feet. At distances of five or six miles apart, passage-places are provided where vessels may remain over-night or turn out to permit others to pass. At the time of this writing it is contemplated to furnish the entire length of the canal with electric lights, so that the channel may be navigated with safety at night. It is only through the rise and fall of the tide—amounting to about 10 feet in the Red Sea—that any current between the two seas is observed, high water in the Red Sea causing a perceptible ebb and flow, which is felt as far as the Great Bitter Lake. The canal is open to vessels of all nations the draught of which does not exceed 24 feet. Steamers use their own engines in making the passage, but sailing-vessels of over fifty tons burden are required to employ a tug-boat. The traffic passing through the canal may be said to be practically confined to steam-vessels. The cost of the canal is estimated to have been one hundred million dollars, which includes the outlay for terminal stations at Port Said, with two breakwaters on the Mediterranean, and at Suez, the Red Sea entrance, which is provided with a breakwater, dry-dock, and other improvements. The work required the excavation of about eighty million cubic yards of material. Figure 5 (*pl.* 52) shows one of the dredges used in the work. The actual operations on the canal were begun in the latter part of the year 1860, and the canal was opened for traffic November 17, 1869.

The New Amsterdam Ship-canal is an important work lately completed in the interests of the port of Amsterdam. It is sixteen and a half miles long, 23 feet deep, and 89 feet wide at the bottom, and is constructed in nearly a straight line from Amsterdam through Lake Y and Wyker Meer to the North Sea.

The North Holland Canal, built 1819–1825, was, until the completion of that just mentioned, the most important canal in Holland. It extends from Amsterdam to the Helder, a distance of fifty miles. It is noteworthy from the fact that it lies below the sea-level; so that vessels require to be locked down in passing from the sea into the canal. It is 78 feet wide at the bottom.

Panama Ship-canal.—Prior to 1875 very thorough surveys of the American isthmus had been made by the engineers of the United States government with the view of determining the best route for a ship-canal between the Atlantic and the Pacific Ocean. A number of promising routes had been carefully examined, including those known as the San Blas, Panama, Atrato, Nicaragua, and Tehuantepec. In 1875 a commission of United States engineers was appointed by President Grant to examine the reports of these surveys, and to recommend the route which they regarded as the most expedient. This commission reported in favor of the Nicaragua route. Some years later, at the instance of De Lesseps, there was convened at Paris an international congress to which representatives of all the commercial nations were invited. By this congress it was decided that a sea-level canal was a *sine qua non*, and that the route from Panama to Colon, the lowest portion of the isthmus, presented the most feasible situation for its construction. As the result of this conference, a French company, of which De Lesseps is the head, was formed for the construction of a sea-level canal across the isthmus at Panama. This enterprise appears from indications at the time of this writing to have been undertaken with an utterly inadequate conception of the magnitude of the work, and has become involved in serious embarrassment, arising partly from the engineering difficulties met with and partly from bad management. After the expenditure of five or six years of labor and of enormous sums of money, the plan of a sea-level canal has been abandoned, and the work is to be completed as a canal with locks. The year 1890 was the time fixed for the completion and opening of the canal, but on account of the failure of the company this date must be considerably deferred.

Nicaragua Ship-canal.—At this time an American company is about to begin the construction of a ship-canal across the isthmus at Nicaragua. This will be a canal with locks, but it is believed that the engineering difficulties will be comparatively few and easily overcome. It is affirmed that, as Lake Nicaragua will afford a deep and navigable channel, only about twenty-eight miles of the ronte will require to be artificially constructed. A plan and a profile of the projected route are shown on Plate 56 (*figs.* 10–12).

Corinth Canal.—Another project of much importance at present under way is the canal across the Isthmus of Corinth. It was begun in 1882 by a French company under contract with the government of Greece. Having a total length of about four miles and joining the Adriatic and the Black Sea, it will shorten the voyage from the Adriatic to Turkey and Asia Minor by one hundred and eighty-five miles.

Manchester and Liverpool Ship-canal.—Of much commercial importance will be the ship-canal which is to connect Manchester with Liverpool. It will begin at Eastham on the south bank of the estuary of the Mersey, which it will follow thirteen and a half miles, and will then pass almost directly to its terminus in the docks at Salford and Manchester. Its total length will be thirty-five miles. It will enable ships of the heaviest tonnage to trade directly with the latter city without the delay of trans-shipment or breakage of bulk. Great advantages to the textile industries of Manchester are expected from its completion.

The Holstein Canal, which will connect the North Sea with the Baltic, and which will be of material service to commerce, was begun in 1887.

Mention may also be made of the plan for a canal to join the Caspian and the Black Sea and of the scheme to join the Bay of Biscay by a ship-canal with the Gulf of Lyons.

Existing European Canals.—Of existing canals, the following enumeration embraces some of the more important: The Eider Canal, twenty-five miles long, between the North Sea and the Baltic; the Ruhr Canal, for the improvement of the navigation of the river Ruhr, forty-five miles long, with fourteen locks; the Ludwig Canal, connecting the Regnitz (a secondary tributary of the Rhine) and the Altmühl (a tributary of the Danube), one hundred and five miles long, with ninety-one locks, and constituting part of a continuous waterway between the Black Sea and the German Ocean; the Mühlroser or Frederick-William's Canal, uniting the Spree and the Oder; the Voorne Canal, in South Holland, which permits the passage of the largest merchantmen directly to

Rotterdam, despite the shallow mouths of the Maas; the before-mentioned North Holland Canal between Amsterdam and the harbor of Nieuwendiep-by-the-Helder, fifty miles long; the Leeds and Liverpool Canal, one hundred and twenty miles long; the Trent and Mersey Canal, one hundred and six miles long; the Oxford Canal, eighty-two miles long, which provides navigation from Coventry to Oxford, while the Grand Junction Canal joins this with the Thames; the Canal du Midi, one hundred and fifty miles long, which unites the waters of the Garonne with the Mediterranean; the Canal du Centre, from Digoin, on the Loire, to Châlons-sur-Saône, seventy-five miles long; the Canal de Bourgogne, uniting the Yonne and the Saône; the Languedoc Canal (1681), between the Bay of Biscay and the Mediterranean, one hundred and forty-eight miles long, with one hundred and two locks, fifty-five aqueducts and ninety-two bridges; and the Rhone-Rhine Canal, over two hundred miles long.

The Canals of the United States, which include many important works in addition to those mentioned below, have exercised a wonderful influence on the development of the internal commerce of the country, and, affording, as they do, the cheapest routes for the transportation of crude materials that can be shipped in bulk, they exert a wholesome regulating influence on the cost of transportation by the railroad lines, with which they are still able to compete. The principal canals in America are the Erie Canal, in the State of New York, joining the waters of the Great Lakes with the Hudson, three hundred and sixty-three miles long; the Champlain Canal, joining Lake Champlain and the Hudson, sixty-six miles long; the Welland Canal, thirty-five miles long, connecting Lakes Erie and Ontario, avoiding Niagara Falls; etc. The influence of the Erie Canal in the development of the Western States of the Union and in promoting the commercial supremacy of New York City is a matter of history.

Inclined Planes have been successfully adopted in place of locks as a means of saving water. They were first introduced in 1789 on the Ketling Canal, in Shropshire, and have been extensively employed in the United States. On the Morris Canal, connecting the Delaware and Hudson Rivers, both locks and incline planes are used. The canal has a total length of one hundred and one miles, the total difference in level being 1557 feet. Of this, 223 feet were overcome by locks and 1334 feet by inclined planes, of which twenty-three are employed on this canal, with gradients of about 1 in 10 and an average lift of 58 feet. The boats are floated upon a cradle mounted on wheels and are easily raised up the incline by water-power.

Figure 4 (*pl.* 52) exhibits the appearance of one of these inclines (with gradients of 1 in 24 and 1 in 12) on the canal connecting the Lake of Drausen at Elbing, in East Prussia, with the Oberland lakes, at Mohrungen and Ostenrode. When at rest, a carriage is in the upper basin of the canal, and one in the lower sunk to such a depth that an approaching boat may be floated upon it and firmly secured thereto by means of chains. The movement of the carriage with its load upon the incline is effected by means of a wire rope driven by a stationary engine placed at the summit of the incline. The carriage conveying the boats runs upon rails, the bed of the cradle being maintained in a horizontal position by giving the front and back set of wheels a different diameter, to neutralize the effect of the incline. By such expedients, heavy canal-boats weighing with their loads from thirty to fifty tons and over are transferred quickly and safely from one level to another. To avoid the objection that has been made to this mode of transference that long and heavily-laden boats would be severely strained when raised out of the water in the manner above described, the cradle is placed in an iron caisson containing water, in which the boat is floated, and in this manner transferred.

Hydraulic Elevator for Canals.—For avoiding the use of locks on canals, Mr. E. Clark, an English engineer, has introduced an ingenious plan, which is found to be specially serviceable in situations where the difference in height to be overcome is so considerable that ordinarily a series of locks would be required. His plan involves the use of a system of elevators by which the boats are raised and lowered vertically by the application of the principle of hydrostatic pressure. The first elevator of this type was built by Clark at Anderton, England, on the Trent and Mersey Canal, and operated so well that it has been adopted elsewhere.

Neufosse Canal Elevator.—A conspicuous example of this system (*pl.* 51, *fig.* 1) is seen on the Neufosse Canal, which connects the ports of Calais, Gravelines, and Dunkerque with the system of canals of the North. The traffic on this canal is enormous (reaching eight hundred thousand tons per annum), and at a point called Les Fontinettes, about two and one-half miles from St. Omer, it was necessary to have a series of five locks, at which boats were often detained for nearly a week waiting their turn to pass. To avoid this serious inconvenience, the administration decided to adopt the plan which Clark introduced at Anderton. This was successfully accomplished. The apparatus consists essentially of two lock-chambers of plate iron. Each of these rests at its centre on the head of a piston which works in the cylinder of a hydraulic press placed in the centre of a well. Communication between the two presses is established or shut off by a sliding valve. When the valve is open, there is a hydrostatic balance. If one of the lock-chambers is more heavily loaded than the other, it descends and forces the lighter one to ascend.

In practice, the upper lock-chamber, with its boat, is always more heavily weighted by the admission of water into it than the chamber and its boat at the lower level, so that, being overweighted, the upper chamber must descend with its burden, while the lower one must of necessity ascend with its load. In operation, a boat is admitted to each of the chambers, one being at the lower and the other at the upper level, and the gates of the canal and of the chambers are closed to isolate the chambers. Now the sliding valve establishing communication between the presses is opened, and the heavier chamber above, which is always surcharged with water ballast, commences to descend, forcing the lower one to rise, until their relative positions have been reversed, when, the transfer having been effected, the closing of the sliding valve holds the chambers in position, and, the gates being opened, the boats may proceed on their respective journeys. The difference of level overcome by the hydraulic lift at Les Fontinettes is 43 feet. The lock-chambers are 130 feet long, 19 feet wide, and 7 feet deep, and they can accommodate boats of three hundred tons burden, the largest that ply the canals of the North. The weight of one of these chambers when filled with water is eight hundred tons, so that a mass of sixteen hundred tons is set in motion at every manœuvre.

Another and more recent example of this system is that erected at La Louvière on the Canal du Centre in Belgium. This lift is even larger than that just described. Its height is 50½ feet; length of the chambers between the gates, 141 feet 7 inches; width, 18⅓ feet; the depth of water, 8½ feet; the diameter of the rams, 6 feet 6¾ inches; the weight to be lifted, eleven hundred tons; and the displacement of the largest boat to be accommodated, four hundred tons. The hydraulic cylinders are each formed of nine lengths of cast iron hooped continuously with steel. The rams are 63 feet 11 inches long, and are formed of eight sections of cast iron 7 feet long and 2.95 inches thick. The lift is operated in the same manner as that above described.

Eads's Projected Ship-railway.—It will doubtless be of interest to many readers to have introduced at this point a brief account of the exceedingly bold and original project of the late Captain James B. Eads (the constructor of the great steel bridge over the Mississippi River at St. Louis, p. 268) for transporting vessels from ocean to ocean across the American isthmus at Tehuantepec (*pl.* 51, *figs.* 4–7). The project has been thwarted to some extent by reason of the death of its chief promoter, but it is by no means improbable that it may one day be realized.

The plans of the Tehuantepec ship-railway are briefly as follows: At each terminus a basin will be excavated leading to a dock. In this dock will be placed a pontoon which, like an ordinary lifting dock, will be capable of raising the vessels. By providing it with longitudinal and transverse bulkheads, it will be given the requisite strength to bear the enormous loads it will be called upon to support. It is proposed to make this pontoon about 450 feet long, 75 feet wide, and from 12 to 15 feet deep. It will be sunk by opening sluice-gates in its sides, and raised by powerful pumps, which will withdraw the water from its interior and discharge it into the surrounding dock or basin. The vertical movements of the pontoon will be guided by large anchor-rods or weighted cylinders securely anchored in the foundations of the dock. They will be constructed in such a manner as to pass freely through the pontoon, but will be separated from its water-spaces, and the heads of these rods will prevent the pontoon from rising above a certain level, and will resist the buoyancy when the vessel has been run off on to the railway.

To lift a vessel from the water without injury to itself, and to place it upon a cradle or carriage for transportation without injury to the carriage, it is necessary to make careful provision to insure the equal distribution of the unequal weight of the vessel, so as to bring no more load upon one part of the carriage than upon another. This result Captain Eads proposed to secure by the use of a system of hydraulic presses built into the pontoon. There will be a number of these presses arranged in longitudinal order and all connected with one another by water-pipes, and by their introduction, it is affirmed, the weight of the vessel, when raised from the water, will be equally distributed over the entire surface of the cradle. The deck of the pontoon will be furnished with six rails for the carriage which will transport the vessel (*pl.* 51, *fig.* 6). The carriage will be mounted upon trucks. It will be provided, also, with a keel-block the entire length of the vessel, hinged in such a manner as to be adjustable to the shape of the vessel's keel. The supports under the keel-block and the other supports of the vessel will rest on large steel rods in which a thread will be cut for an adjusting nut, and the upper ends of these rods under the vessel's bottom will carry on a universal joint a bearing-block having an area of 12 square feet. These bearings will be adjusted in position against the vessel's bottom. They will be cushioned with rubber, to form a firm yet elastic support.

The operation of lifting a vessel will be about as follows: The carriage will be run from the railway upon the pontoon and locked in position (*fig.* 4). The water will then be let into the pontoon by the sluice-gates, and it will go down with the carriage resting upon it until it has reached a sufficient depth to allow the vessel to be floated in over it. The vessel will then be brought in over the pontoon with the centre of gravity over the centre of the pontoon, and adjustable guides from the sides of the dock worked by hydraulic power will bring the vessel into position centrally over the carriage. The pontoon pumps will now be set to work, and the pontoon, with the carriage upon it, will rise up under the vessel, and just previous to actual contact with it the pressure pumps will be set to work and the entire system of rams will be forced up against the keel, bottom, bilges, and sides of the vessel. The pontoon pumps will continue to lift the pontoon out of the water with the vessel upon it until the latter has reached the proper height; the adjusting nuts before described will be run down on the thread of the supports until they have a firm bearing on the cross-guides of the carriage. When this has been done, the valves of the rams will be opened, the rams will recede downward into the pontoon, and the weight of the vessel will then have been transferred from the rams to the carriage (*fig.* 5).

The vessel will now be ready to be transported on the railway. This will be specially constructed with substantial foundations of road-bed, and will be furnished with six tracks of ordinary gauge. The rails, which will be of steel, will be extra heavy (one hundred and twenty pounds to the yard), and will rest on steel cross-ties extending across all six tracks. The width of the roadway will be about 50 feet. The wheels of the carriage trucks will be double-flanged, to lessen the liability to derailment. The motive-power will be obtained from locomotives of exceptionally great tractive power which will impose a weight of at least one hundred tons on the driving-wheels. These locomotives will be attached directly to the load, three in front (*fig.* 7), and three behind, as pushers, if necessary. As any pronounced deflection from a straight line will be attended with risk, an ingenious device in the form of a floating turn-table has been proposed, to permit of the turning out of a vessel to allow another to pass or to permit of a change of direction. To float the vessel free from the carriage in the waters of the opposite ocean, when it reaches the dock at the other terminus of the line the same series of operations will be gone through with, but in reverse order.

It should be stated, in conclusion of the description of this ingenious scheme, that some doubts have been expressed among naval engineers as to the ability of vessels to withstand uninjured the strain of such treatment as they would be subjected to in this system of land transport.

6. DRAINAGE AND IRRIGATION.

The Object of Drainage is to dry swampy or low-lying lands which may be saturated or wholly covered with water, or which may be subject to overflow. By this means the ends of agriculture are served by winning for cultivation the lands reclaimed; and there is also accomplished the no less important result of improving the sanitary condition of localities by removing the cause of noxious exhalations.

Swamps owe their origin to various circumstances, among which, naturally, insufficient drainage is the principal cause. Wherever the rain-water, or that flowing in from surrounding localities, or the water of springs, collects in a basin the floor of which is formed of impenetrable strata, this accession of water, if not counterbalanced by evaporation, the growth of vegetation, or efflux, will form either a lake of considerable magnitude or a marsh in which will flourish a rank growth of aquatic vegetation. In process of time the annual development of the plants and the accumulation of their partially-decomposed remains give origin to the so-called "peat bogs."

Extension of Swamps.—By the gradual deposition of sediment brought by streams discharging into ponds or lakes, the latter, in time, may become almost completely silted up; in such cases the former lake or pond is converted into marsh-land by the rank growth of aquatic and semi-aquatic vegetation. At the same time, in consequence of the silting up of the outlet channel, the outflow is restricted, and the damming back of the inflowing water causes it to spread out laterally, thus laying the foundation for the further extension of the marsh.

Hindrances to Drainage.—Generally speaking, the rise of the river-bottoms by reason of the gradual deposition of the sediment carried by the flowing water, and the damming back of the waters thus occasioned, are the principal causes of the hindrance of the natural drainage of rivers and creeks, and of the consequent conversion of extensive districts into swamps. Apart from this, hindrances to drainage are caused when, for example, the waters of tributary streams are dammed up by the occurrence of floods in the main river, or when the mouths of rivers discharging into the sea are closed by sand-banks or bars thrown up by the action of the waves. The river must in such cases make a *détour* around or pass over the obstacle, its course being consequently lengthened, its fall diminished, and the rapid efflux of its waters impeded.

Drainage Plans.—In making plans for the drainage of a given locality, there must first be gathered a thorough and accurate knowledge of the causes leading to the formation of the swamp or body of water, also of the nature of the bottom and of the sub-soil, of the annual rainfall, etc. Furthermore, accurate observations of the level of the locality in relation to that of its surrounding territory must be made, that the amount of available fall may be determined.

Drainage Works.—The actual operation of drainage consists either in lowering the level of the water or in elevating the ground. The lowering of the water-level is the more usual and the simpler plan, and is effected in various ways, according to circumstances. Should the swamp be caused by the silting of the bottom of an adjacent river, the attempt will be made to lower the water-level of the stream by shortening its course or by other well-known expedients (see River Engineering, p. 298), and drainage-canals communicating with the stream will be dug, through which the waters of the swampy or submerged district will be drained into the latter. To obtain the needful fall, it will frequently be found necessary to give the drainage-canals considerable length and a circuitous route, and to locate at some distance down the stream the outlets, which must be provided with locks, to prevent the entrance of tide-water from the river. The lowering of the level of many lakes in mountainous regions is expeditiously accomplished by cutting through the rock-barrier which like a natural dam retains the waters (for example, the Lake of Lugano, in Switzerland).

To prevent as much as possible the incursion of water upon the reclaimed land, as well as to reduce the volume there accumulated, the water-courses traversing the territory are as far as practicable intercepted and made to pass around the lowlands by diverting them—often at considerable expense—into new channels.

Open-drainage Systems.—The plan most commonly followed for lowering the water-level of a locality consists in establishing a network of canals so disposed that the smaller shall open into the larger, these, in turn, into the creeks and lesser streams, and these into the rivers, thus affording a connected system of outlet channels. This system can be applied only where the available fall is sufficient for carrying it into effect. That the lateral channels opening into it may be given the greatest possible fall, the main drainage-channel follows the line of the deepest depression in the marsh. As the size of the drainage-channels will depend on the quantity of water to be drained, they must be cut deep enough to obtain the required lowering of the water-level over the entire drained area. For a meadow the water-level should be about 15 inches below the ground-surface, and for cultivated land about 4 feet.

Covered-drainage Systems.—Instead of the above-described open-drainage canals, covered channels or drains are frequently employed. This plan is especially adapted for clayey soils devoted to agricultural uses, for in such cases the distance between the canals must necessarily be small, and open channels, aside from other objections, would involve the loss of much land valuable for agricultural uses. These covered drains—which are placed at a suitable depth and have the necessary fall—constitute a series of hollow spaces in which the soil-water collects and is finally discharged into ditches with which they communicate. For this purpose it is customary to use tubes of baked clay a few inches in diameter, made in sections from 1 foot to 1½ feet in length, which, being laid end to end in trenches of proper depth and suitable width, are covered with earth. The ends of these tubes are fitted together with a collar which holds them snugly enough in place, but still permits the entrance of water by percolation through the joints. As the surrounding soil is more difficult of penetration than the openings about the joints of the tubes, the soil-water collects in these, and is conveyed to the drainage-canal provided for it. The depth at which this underdraining should be located will depend upon the nature of the ground and the kind of cultivation to which it is to be subjected. The depth should not be less than 2 feet. The small drains just described (suction-drains) communicate with larger ones (collecting-drains); the former follow the direction of the greatest fall. This should be at least .04 per cent. for tubes of one inch diameter, and the distance apart should be from 10 to 40 feet. In place of the above-described tubes of baked clay, hollow tiles are employed for the same purpose, and likewise canals filled with small stones; in firm clayey soil simple hollows, left unfilled, have been used, but no reliance can be placed upon their permanence.

Artificial Drainage.—If the water-surface lies too low to permit of drainage by utilizing a natural outlet, recourse must be had to appliances for artificially raising the water. Of these, the most commonly used are bucket-wheels, Archimedean screws, and especially pumps (centrifugal pumps, among others). The motive-power for operating these machines is to some extent still furnished by the wind, by water-power, or by animals. For important works of this nature, however, powerful steam-engines are employed. One of the most extensive operations of this kind is the drainage of the Haarlem Lake, in Holland, which covered an area of seventy-two square miles. To effect this, the meer was first isolated by constructing about it a strong circular dyke, around which was built a canal thirty-nine miles in length. This communicated with Lake Y, and with all the canals which conduct the water of the meer to the North Sea. Three pumping-engines of four hundred horse-power each raise the water from the lake, and two others lift the water out of the surrounding canal into Lake Y, where, on account of the tides, the level of the sea outside is higher than that of the canal. Nine hundred and forty-six million cubic yards of water were pumped out in somewhat more than three years. The machinery is now required merely to prevent the further accumulation of water, and is operated during only a few months of the year.

At the present time, it is said, the Dutch government has under consideration the drainage of the Zuyder Zee—a project of even greater magnitude and importance than that of the Haarlem Meer. The preliminary studies have been carefully made under the direction of the government engineers, who have pronounced the project to be technically and economically feasible. The area to be drained, and thus recovered for the purposes of agriculture, embraces nearly four hundred thousand acres, and is covered with water to an average depth of 13 feet. It is estimated that to effect this colossal work ninety-four hundred horse-power, divided between sixty-three steam pumping-engines of one hundred and fifty horse-power each, will be required. The time for the complete drainage of the area is placed at twenty-one months, and the cost is estimated at 116,000,000 Dutch guldens ($46,000,000).

Sewerage.—Among drainage works must be included the covered canals or sewers under the streets of cities. These are intended to carry off underground and to conduct to the river or the sea the rain-water and the sewage, which otherwise would have to run off in the open gutters. There is some difference of opinion among engineers as to the propriety of using two systems of channels, or of discharging both rain-water and sewage through the same channels. The first is known as the "separate" system; the latter, as the "combined" system. Both have their advocates. In the separate system in operation in the city of Paris, the rain-water and all the ordinary waste-water of the houses are led into the sewers, but the excreta from four-fifths of the population and the solid portions from the remaining fifth are excluded, and are removed in closed casks or retained in cesspools, from which they are pumped by odorless excavators. The municipal engineers of Paris, however, are said to favor complete water-carriage, and the changes that are constantly being made have in view the ultimate adoption of this system. In Germany opinions of municipal engineers differ as to whether it is better to remove the excreta by means of casks (usually termed "dry removal") or through the sewers (termed "water-carriage"), and both systems are in vogue.

Liernur System of Sewerage.—In the so-called "Liernur" system the separate plan is developed to the highest state of perfection. In this, the excreta and a certain portion of the house waste-water are led into a system of iron pipes and removed pneumatically by means of an engine at a central station. The remaining house-water, together with the rain-water, is carried off through a separate system of brick sewers.

Each of the plans, as indicated above, has its advocates, and the question of deciding between them should be determined by an examination of the conditions prevailing in each locality.

Construction of Sewers.—The fall of the sewers should be as great as possible, though the nature of the ground often compels the engineer to lay them almost horizontally. That they may be kept constantly free and as clean as possible, they should be so constructed that they can be entered and inspected. The bottoms should be smooth, solid, and impervious, and as far as practicable the entire channel should be provided with smooth interior surfaces. Figure 20 (*pl.* 57) is a view of a sewer with an oval section, showing the mode of connecting the street-gutters. Figure 10 shows a sewer of circular section, over which is placed a subterranean footway; Figure 21 shows a section of one of the main collecting-sewers of Paris, with lateral footways for convenience of inspection. Of the two smaller cement-pipes seen at the sides, one is designed for the under-drainage of the sandy soil of the city, and the other for the future application of a system of universal underground drainage of excreta.

The Cleansing of the Sewers is effected mainly by flushing, there being stored for the purpose a large body of water, which at stated intervals is suddenly let into the sewer, and which washes out the deposited sediment. This flushing process is sometimes accomplished naturally by the tide where the mouths of the sewers terminate in waters subject to ebb and flow. At convenient distances apart, the sewers are provided with man-holes or entrance-shafts to give admission to those charged with the work of inspecting, repairing, and cleansing them, and in most cases, also, air-shafts are provided, to insure ventilation.

Colusatage.—The drying of soils by elevation of the ground-surface may frequently be applicable in situations where the above-described plans for drainage are found to be inadmissible. This method has incidentally the advantage of permitting the soil to be improved at the same time, so as to fit it at once for cultivation. There are several ways in which this process may be carried on. In one of these the filling material is transported from other localities by men or by draught-animals, but this method, being comparatively costly, is confined to surfaces of limited area. In the other—which is more generally followed, and is applicable to surfaces of considerable extent—the filling is effected by artificially flooding the lowland with the silt-laden waters of adjacent streams. By means of embankments and ditches judiciously disposed, the muddy flood-waters of such streams are conducted to and distributed over the surface upon which it is desired they shall deposit their solid matter. This process—termed by Continental engineers "colusatage"—has occasionally been successfully applied on an extensive scale; as, for example, in the Chiana River Valley, in Central Italy, and the marshes of Grossotto, in Northern Italy.

Irrigation.—In many regions destitute of adequate rainfall, and therefore naturally unfitted for agriculture, the deficiency of moisture is made good by artificial irrigation. In this way in various quarters of the world vast tracts of land which otherwise would be useless and uninhabitable have been made extremely fertile and rendered capable of supporting a teeming agricultural population. This result is attained either by the method of flooding or by that of regulated distribution, as the circumstances or the situation determines.

Irrigation by Flooding is resorted to very freely in hot countries, and especially in regions adapted for grain-growing, as in Egypt, Southern France, and Italy, the surface being submerged at the proper season by releasing the water confined behind suitably-located dams and embankments. The area is kept flooded long enough thoroughly to saturate the ground to a suitable depth. Meadow-lands are flooded during the winter season. This method of irrigation has been brought to great perfection in Lombardy, where the waters of the streams descending from the Alps are most thoroughly utilized for this purpose. As a typical example of this system of irrigation, the Cavour Canal should be named (*pl.* 52, *fig.* 1). This proceeds from the river Po at Chivasso, near Turin, and is carried over a large number of aqueducts and conducted through numerous tunnels. It has a maximum breadth of 13 feet (at its embouchure) and a maximum depth of 11 feet. It draws from the Po about 4000 cubic feet of water per second.

Irrigation by Distribution.—In another system of irrigation the water is distributed over the surface under cultivation in regulable quantities as it may be needed from time to time. The supply is usually obtained from artificial reservoirs formed by damming the waters of mountain-streams in narrow valleys or gorges, and the impounded water is conducted through open or covered channels, sometimes over great distances, and by suitably-disposed channels ramifying from the main conduits is distributed over an extensive surface. In this manner large tracts of land may be kept at all times supplied with the moisture necessary to insure their fertility, and with comparatively little waste of water, provided only that the natural fall is favorable for the purpose. Where this is not the case, it will be necessary, wherever it is practicable, properly to grade the surface to be irrigated. In the disposition of the works of this order, the distributing-canals are conducted along the summits of the ridges or slopes, the drainage-ditches being situated at the bases of the slopes, and between these are placed a number of smaller parallel ditches, which gradually fill up with water and overflow. The water is permitted to flow a certain number of days in the year, according to the character of the climate, the soil, the kind of crops that are cultivated, etc. The overflow water may be utilized for irrigating lands at a lower level, and this process may be several times repeated.

Irrigation Works in the United States.—In the United States irrigation is practised to some extent in Colorado, New Mexico, and California. In the arid sections of the south-western portion of this country, the remains of great artificial channels testify to the former existence of extensive irrigation works constructed by the race which prior to historic times inhabited the region. It is of interest to note in this place that recently a great scheme for the irrigation of the arid lands lying between the Rocky Mountains and the Missouri River has been proposed by Major Powell, director of the United States Geological Survey. This region embraces several hundred thousand square miles of territory, all of which in their present condition are unfit for cultivation. The plan contemplates the construction of great dams in the cañons of the rivers, at suitable points near their head-waters. These would be built sufficiently strong to resist the flood-waters of spring, and behind them would be impounded immense volumes of water, which by means of aqueducts, canals, etc., could be distributed over the entire region. All that is needed, apparently, to render these vast tracts fruitful is the moisture at present lacking, and the scheme presents splendid possibilities. The director expresses the belief that by the proper application of his plans not less than one hundred and fifty thousand square miles of desert-lands could be made productive, thus increasing by one-third the area of the agricultural lands of the country. It appears possible at this writing that Congress will appropriate a generous sum of money to provide for the cost of making the preliminary surveys required to determine the feasibility of this great project, the actual realization of which would be a triumph of science as magnificent as it would be beneficent.

Sewage for Irrigation Purposes.—At the present day not only the natural watercourses, but also the sewer-waters of cities and towns, are utilized for purposes of irrigation. Formerly it was the universal practice to permit the sewers to discharge their volumes of impure water into the nearest watercourse, regardless of whether the volume of water in the stream was large enough to dilute the impurities below the dangerous point, or whether—as is the case in London, where the backing up of the sewage by the tide occurred—in consequence of this, the conditions brought about were most unwholesome and intolerable. In certain localities in England and France the sewage, for the purpose of utilizing its fertilizing properties, is conducted in separate conduits and distributed over the fields. The most extensive system of this order, however, has lately been put in operation by the authorities of the city of Berlin, where all the sewage from the built-up portions of the city is conveyed in the sewers to pumping stations conveniently located for the purpose, whence the waste waters are distributed over a considerable area of fields devoted to the purpose in the adjacent country. Other plans involving the precipitation of the organic matter and its separation by chemical treatment, that it may be utilized and that at the same time the water may be purified, are also in use to a limited extent.

It appears, however, that, while methods similar to the above have been successfully employed for the disposal of the sewage of towns and small cities, until the Berlin experiment had been made successful it had not been found practicable to apply them to the treatment of the enormous volumes daily discharged through the sewers of the great cities. For the effectual disposal of the latter in such a manner as completely to guard the health of the inhabitants no plan that is universally applicable has yet been devised. For cities situated upon or near the sea-coast, the plan of pumping the sewage into artificial reservoirs placed at a convenient point in the harbors, from which it is discharged into the sea and carried out at ebb tide, affords a system as nearly perfect as could be devised; but for inland cities, where the sewage must be discharged into the adjacent rivers, the only practical plan seems to be its dilution by frequent periodical flushings, and its subsequent discharge into the stream at a point so remote as to reduce to a minimum the danger of its return by the tide. Fortunately, the flowing water in the channels of the rivers very quickly purifies itself by aëration; and this natural process is so efficacious that even the water of the river Thames, charged with the vast volume of sewage constantly discharged into it from the sewers of London, is found to have become sufficiently pure for drinking purposes five miles below the city. Should the Berlin experiment be found to continue to answer its intended purpose—which now appears probable—it may teach an important lesson in the disposal of the sewage of great cities.

7. Water-supply.

A. Wells and Well-boring.

Cisterns.—To obtain the requisite supplies of water in localities destitute of natural springs or of springs that yield sufficiently, and where the water of artificial wells is poor in quality, recourse must be had to cisterns. These watertight covered reservoirs for the storage of rain-water are placed where they will be convenient of access and protected from heat and frost. They may be of any desired form and size, and where they are employed upon a large scale a number may be arranged side by side, in which case the division-walls between them will serve as abutments to support the structure. That the walls and bottom of the cistern may be watertight, they are built of hard-burned bricks laid in good hydraulic cement and covered on the inside to the depth of from one-half to three-fourths of an inch with a layer of quick-setting cement. The supply of the cistern will depend upon the amount of rainfall. (See River Engineering, p. 293.)

Spring-wells.—It often happens that the surface of the ground will appear to be poorly supplied with water even though water-bearing strata may be present at comparatively slight depths, for the reason that the so-called "ground-water" reaches the surface naturally only where the ground-formation is especially favorable. To utilize this subterranean water for drinking and household purposes, there is sunk to it a well, whose sides are properly protected from caving in. The construction of the well assumes the simplest form when it is required to enclose the waters of a flowing spring. The stratum of sand or gravel through which the water flows is merely excavated so far as to allow of the collection of a body of water deep enough to be taken out conveniently by baling or otherwise. The walls of these spring-wells need to be carried down only far enough to obtain a firm foundation; to prevent the softening of the surrounding soil by the overflow, a side-channel should be provided to carry off the surplus.

Pump-wells.—Deeper wells are built either by excavating the well-shaft, lining the interior of the same with timbers, to prevent caving in, and then raising a cylindrical wall of masonry from below upward upon a timber foundation, the hollow space between the wooden shaft-lining and the masonry being filled in with earth, or by sinking the well if the water-bearing strata are found near the ground-surface. For this purpose an excavation is made from the surface down to the level of the water-bearing stratum, and around the wall of this excavation several stout planks are placed, one above another, upon which the wall of masonry is built. By excavating beneath the timber foundation with boring or digging tools or with the sand-pump, the cylinder of masonry is caused slowly to settle down, the walling being continued upward as fast as the sinking progresses, until the required depth is reached. When the well is completed, the pump, pump-tube, and other appliances are put in place.

Driven Wells.—A driven, or tube, well, consists essentially of a strong pipe of wrought iron perforated about its lower end with a number of small holes and terminating below in a sharp point of steel (*pl.* 53, *figs.* 1–3). This tube is driven into the earth with a small pile-driver hammer (*fig.* 3) until a water-bearing stratum is reached. Where the depth exceeds the length of the tube, a second section is screwed to the top of the first, and the driving is continued. When the needful supply is found, a small suction-pump (*fig.* 2) is attached to the top of the tube. This mode of obtaining water is very widely practised throughout the agricultural regions of the United States wherever the nature of the ground will admit. The English army found driven wells very serviceable in its Abyssinian campaign. In Minneapolis, in situations beyond the reach of the city water-service, a number of such wells, placed about 15 feet from a centre, with their delivery-pipes joined at the top, are used to obtain a supply of water for extinguishing fires.

Artesian Wells are perpendicular perforations or borings through a succession of strata deep enough to reach subterranean bodies of water whose sources are higher than the places where the perforations are made, the water being forced to the surface, and often to a considerable height above it by hydrostatic pressure. The name "artesian" is derived from Artois (the ancient Artesium), in France, where the art of sinking these wells is believed first to have been practised in Europe. But traces of deep borings discovered in Lombardy, Asia Minor, Egypt, and the Desert of Sahara testify that the art was known in more ancient times. In China it has been practised from an unknown period. In the province of Ou-Tong-Kiao it is reported that there are artesian wells from 1500 to 1800 feet deep.

Phenomenon and Principle.—The phenomenon of artesian wells can be exhibited only when the underground configuration of the strata is favorable, as where they form a basin. The principle of their action is about as follows: A succession of strata, some permeable and others impermeable to water, incline downward so as to form a species of trough or basin (*fig.* 13). The rain-water, falling on the exposed edges of these strata where they outcrop in the more elevated land that forms the rim of the basin, permeates the pervious layers of sand, gravel, chalk, etc., until it is arrested in its downward course by an impervious stratum of rock or clay. The water thus imprisoned accumulates in the pervious stratum as in a reservoir; and if a well be bored within the boundaries of the basin, so as to tap this stratum, the water, by the hydrostatic pressure of the semi-liquid column acting upon it, will be forced up to, and sometimes even considerably above, the surface of the ground, the height depending upon the elevation of the rim of the basin above the location of the well. London and Paris are both situated upon natural basins of this description, and artesian wells in great numbers have been bored in these cities and the contiguous country.

Double Artesian Wells.—The term "artesian well," as is apparent from what has preceded, should be applied only to bored wells in which the water rises to the surface or to some distance above the surface. It frequently happens, as in the London basin, where numerous wells have been bored in the same neighborhood, that those toward the rim of the basin (*pl.* 53, *fig.* 13)—that is, in its higher portion—cease to flow naturally. Furthermore, it often happens that a number of water-bearing strata will be penetrated before one is reached that will deliver the water from the surface; or it may be that the boring will require to be continued through a number of productive strata because the water yielded by them is insufficient in quantity or objectionable in quality. Occasionally the supply from two levels is utilized through the same bore-hole by carrying a smaller tube down inside a larger one and continuing it to a lower stratum. A double artesian well of this kind is shown in Figure 8.

Artesian-well Boring: Tools.—The method of boring artesian wells has been greatly improved in recent years, more especially in the United States, where vast numbers have been bored in search of petroleum. The modern practice of artesian-well boring is given in the following description, which is abridged from Trautwine: Deep vertical perforations in earth and rock from 6 to 8 inches in diameter, such as are required for artesian wells for water and oil, and for mining explorations, are drilled by repeatedly lifting and dropping in the same vertical line a heavy iron bit with a steel cutting-edge (*fig.* 5). To insure roundness of the bore, the bit is partly revolved horizontally after each blow. The length of the cutting-edge of the bit is a little greater than the diameter of the bit itself, and consequently the well-bore is made sufficiently large to prevent the binding of the bit. The bit is the lowest member of a series of iron and steel bars screwed together at the ends and called a string of tools (*figs.* 4–7).

The String of Tools varies in length from 25 to 60 feet, according to the size and depth of the well-bore and the hardness of the rock; and its diameter throughout (above the cutting-edge) is an inch or two less than that of the bore. The weight of the string of tools is from 800 to 4000 pounds. The uppermost member is always a "rope-socket" *without* a swivel (*fig.* 6), to which the lower end of the supporting rope-cable is attached. This cable passes up and out to a horizontal lever, which by means of a horse-power or steam engine is kept constantly moving up and down with a see-saw motion. The string of tools, with the cutting-edge of the bit at its lower end, is thus alternately lifted from 2 to 4 feet and let fall from thirty to fifty times per minute, and so drills its way into the rock or earth. A depth of from 4 to 10 feet of water is required in the well to facilitate the drilling and the removal of the *débris*. After water is reached the drilling may be continued even if the bore-hole is full of water; but a great depth of water diminishes the force of the blows.

A suitable arrangement must be provided for paying out the rope as the boring-tool descends. A clamp is attached to the cable, and the man in charge, by turning the clamp, twists the rope, and thus turns the bit horizontally about one-fifth of a revolution after each stroke until six or eight complete revolutions have been made in one direction. He then reverses the motion, making an equal number of turns in the opposite direction.

Sand-pump.—After drilling a few feet, the string of tools is lifted out by means of the cable, to allow of the removal of the *débris*. This is done with the sand-pump, which is a sheet-iron cylinder, say 4 inches in diameter and from 4 to 6 feet long, provided at its foot with a valve opening upward. This pump is lowered to the bottom of the bore and filled with the mixed water and *débris* by churning it up and down a number of times. The pump is then lifted out and emptied. The string of tools is again lowered and the drilling resumed. The *débris* must be removed after each 3 or 5 feet of drilling.

Spudding.—The same operations are followed in drilling through the earth before the rock is reached. This is called "spudding." In this case the sides of the bore-hole must be protected from caving in. For this purpose a wrought-iron pipe ¼ of an inch thick and of such a diameter as to fit the hole closely, is inserted, and is driven down with a heavy oaken maul as the drilling proceeds. One end of the maul is attached to the lower end of the cable which during drilling supports the string of tools, and is repeatedly lifted and dropped upon the head of the tube, which is protected by a cast-iron "driving-cap." The foot of the tube is shod with a steel cutting-edge ring. When the tube has been driven as far as it will readily go, the maul is removed from the end of the rope, the string of tools substituted, and the drilling resumed inside the pipe. The pipe is put together in lengths of from 8 to 18 feet, and the drilling and pipe-driving proceed alternately until the rock is reached and the foot of the pipe forced into it far enough to shut off quicksand or surface-water. For overcoming special difficulties there are employed appropriate tools and devices which need not here be considered.

Deep-well Boring: Derrick.—For wells from 1000 to 3000 feet deep there is used a stationary machine with a walking-beam, similar to the machines employed in the oil-regions of Pennsylvania. A square pyramidal derrick is erected, 74 feet high, 20 feet square at the base, and 4 feet square at the top. The four corner legs, made of stout planks spiked together, are strongly braced by horizontal and diagonal timbers. The timber walking-beam is 26 feet long, 12 inches wide, and 26 inches deep at the middle, and is pivoted to the top of a stout wooden post 12 feet high, called the "samson-post," which is dovetailed at its foot into the main-sill of the machine.

Motive-Power and Tools.—The motive-power is a fifteen-horse-power steam-engine, which, by means of a belt and pulley, crank, and pitman working at one end of the walking-beam, gives to the latter its see-saw motion. To the other end of the beam, and immediately over the well, is suspended, by means of a hook, a "temper-screw." This is composed of two bars of iron (5.8 by 2 inches in diameter and 2 feet long), hung 2 inches apart, fastened together at their top ends, at which point there is an eye, which is suspended on the walking-beam hook. At the bottom of the two bars there is a sleeve-nut, and between the two bars and passing through the nut is a screw 5 feet long, at the bottom of which there is a head carrying a swivel, a set-screw, and a pair of clamps. These grasp the cable (2 or 2½ inches thick) which carries at its lower end the string of tools. This, for a 2000-foot well, consists of a steel bit 3 or 4 feet long, weighing from two hundred to four hundred pounds; an auger-stem of 4- or 5-inch round iron from 24 to 30 feet long, weighing from twelve hundred to twenty-one hundred pounds; steel-lined drill-jars 8 feet long, weighing from six hundred to seven hundred pounds; a sinker-bar of round iron, of the same diameter as the auger-stem, 12 feet long and weighing from six hundred to eleven hundred pounds; and a rope-socket 2½ feet long, weighing two hundred pounds. The total length of the string of tools is from 50 to 60 feet; total weight, three thousand pounds, or, for an 8-inch bore in the hardest rock, four thousand pounds. The sinker-bar is added to give additional weight in lowering the string of tools and in working the drill-jars. The other tools are similar in form to those above described. (See *pl.* 53, *figs.* 4–7.)

The Drilling-cable is wound round a drum called a "bull-wheel shaft," at the foot of and inside the derrick. While drilling is going on, the cable passes from the bull-wheel shaft loosely over the sheave at the top of the derrick and down to the clamps at the lower end of the temper-screw on the end of the walking-beam. As the drilling progresses the temper-screw is turned or fed out by the man in charge, who by means of a clamp twists the rope so as to change the position of the bit after each stroke.

Removal of Tools.—When the tools have to be lifted out, the cable is disengaged from the clamps on the temper-screw, and is wound upon the bull-wheel shaft, which for the purpose is thrown into gear with the steam-engine, the pitman being at the same time removed from the crank-pin, so that the walking-beam is at rest. For catching and withdrawing broken bits or articles accidentally dropped into the drill-hole, for enlarging or strengthening the bore, etc., ingenious special tools are provided.

It may sometimes be found advantageous not to commence the boring directly at the surface, but, instead, an open pit or shaft may be dug of any convenient depth and with sloping sides (widest at the top), and from the bottom of this the boring may be started. By this plan tube-sections of considerable length may be used without the aid of a very high derrick.

The Diamond Drill is employed to some extent for artesian-well boring. With this ingenious apparatus the hardest rock may easily be penetrated. The drilling-tool consists of a metallic stock or holder in the form of a cylindrical tube, either open at the cutting-end, with angular fragments of black diamonds embedded in the metal at intervals around the inner and outer edges of the ring in such a manner that cutting-faces of the stone shall project (*pl.* 53, *fig.* 12), or so closed at its extremity as to present a convex surface studded around with the fragments of the cutting substance. The tubular form of the drilling-tool affords the special advantage of preserving a perfect record of the various strata through which the drill has passed, since the "core" (*fig.* 11) which it cuts out of the rocks may be broken off and lifted with special tools from time to time, and its parts, being properly placed together, will form a continuous solid cylinder clearly exhibiting the character and successive order of the strata passed through.

London Artesian Wells.—To obtain the pure water-supplies stored in the underlying chalk-formation at a depth of from 60 to 900 feet, the strata of the London basin have been penetrated by great numbers of artesian wells. From these sources the Bank of England, the fountains of Trafalgar Square, a number of public institutions, and many of the great breweries of London obtain their supplies. So numerous are the wells in this circumscribed area, and so great is their drain upon the underground reservoirs, that it is not surprising that the general level to which the water formerly rose in the London district has within recent years so very sensibly lowered that from many wells whence it formerly flowed the water now requires to be raised by pumping.

French Artesian Wells.—In France there are many artesian wells, some of them of notable size and productiveness. That at Grenelle, near Paris, commenced in 1834 and finished in 1841, is carried to the depth of 1798 feet and flows at the rate of six hundred gallons per minute, furnishing a valuable source of water-supply to this suburb. The water of this well is horizontally conveyed to the centre of the Place de Breteuil, Paris, where the open-work tower of bronzed cast iron, of elegant design (*pl.* 6, *fig.* 3), encloses the ascension and distributing pipes. (See p. 63.) The artesian well at Passy (also near Paris), commenced in 1855, was carried through the chalk into the lower greensand to the entire depth of 1923 feet, the bore finishing with the enormous diameter of 2⅓ feet. This is probably the largest artesian well in the world. It required nearly seven years to complete the boring. At one time the well yielded 5,582,000 gallons of water every twenty-four hours, but this fell off to 3,795,000 gallons, at which rate it has since continued to flow, and feeds the lakes of the Bois de Boulogne. The well at St. Ouen delivers water from two levels, a smaller pipe being passed inside the first and carried some distance farther down. Both of these streams supply the canal-basin at St. Ouen, which lies above the level of the Seine.

German Artesian Wells.—In Germany the artesian salt-spring at Kissingen, in Bavaria, (1832–1850), is one of the most noteworthy. It reaches a depth of about 2000 feet, and ejects a stream of brine, at the rate of six hundred and fifty gallons per minute, to a height of 58 feet. The piping in this well is concentric, the water being forced to pass up between the outer and the middle tube, then down between the middle and the inner one to the rock-salt stratum, where it saturates itself with salt, and finally up through the inner tube, from which it is delivered. The pressure in this well is believed to be caused by carbonic-acid gas. The boring at Sperenberg, near Berlin, was undertaken to obtain a supply of rock-salt. The well-bore was carried down with a diameter of ·16 feet to the depth of 280 feet, at which depth the salt-bed was reached. It was continued with the same diameter through the salt 680 feet farther, then reduced to 13 inches and driven to the unparalleled depth of 4194 feet without having perforated the salt-bed.

African Artesian Wells.—In the oases of Sahara, in Africa, there are evidences of the former existence of many artesian wells, some of which, recently opened, have a depth of 360 to 480 feet. Since 1858, French engineers have been successfully engaged in the beneficent work of sinking numerous artesian wells in the sandy plains of the Great Desert. Supplies of water are found in abundance at comparatively small depths, and in the brief period which has elapsed since these wells were bored the changes they have wrought have been most surprising, the fertilizing streams having converted into fruitful tracts many stretches of desert plains.

American Artesian Wells.—In the United States there are some noteworthy artesian wells. In St. Louis the authorities have carried a boring at the county buildings to the depth of 3235 feet without obtaining water. In one of the sugar-refineries in the same city is a well 2197 feet in depth, delivering a body of salty water to the height of 75 feet above the surface. In Chicago are two wells, respectively 700 and 1000 feet deep, yielding nearly one million gallons of pure cold water (57° F.) daily, with a head of 125 feet above the lake-level. At Louisville, Kentucky, is a very productive well which is carried to a depth of over 2000 feet. A well at Charleston, South Carolina, is 1250 feet deep, and delivers twelve hundred gallons an hour to the height of 10 feet above the surface. In Philadelphia there are several artesian wells, of which one in the Continental Hotel, with a diameter of 8 inches and a depth of 200 feet, yields fifty thousand gallons per day.

It may be noticed, in conclusion, that for obtaining water-supplies for irrigation and other purposes in the arid region of the Western United States it has been proposed to adopt a plan similar to that practised so successfully in the Desert of Sahara. Thus far, it has been tried only in isolated cases, and the results obtained have attracted no special attention.

B. WATER: ITS PURIFICATION, STORAGE, AND DISTRIBUTION.

Quality of Water.—Respecting the quality of water for town and city supplies, the following conditions are prerequisite: It should be transparent, inodorous, cool, and soft; it should contain but little dissolved solid matter, and should be free from organic substances. Chlorine and nitrogen compounds of the alkalies should be tolerated only in extremely small quantities, inasmuch as their presence is an almost positive indication of contamination by organic impurities (sewage). While the wholesomeness of water for drinking purposes may not be materially affected by the presence of salts of lime and magnesia, it may be rendered thereby quite unsuitable for many domestic and industrial uses.

Hard and Soft Water.—Water containing notable quantities of the salts of the alkaline earths (lime, magnesia) is distinguished as "hard" water; when these salts are absent, or present only in very minute quantities, the water is termed "soft." In consequence of the presence of these compounds, hard water, when treated with a solution of soap, will decompose it, and there will be formed insoluble lime and magnesia soaps, which are precipitated. As no soap remains in solution, the water will not form suds until a quantity of soap has been added in excess of that required to precipitate all the lime and magnesia present. Consequently, such water is unsuited for washing. Furthermore, hard water, when evaporated by boiling, has the undesirable property of leaving behind it solid matter in the form of a residuum which attaches itself to the surfaces of the vessel, forming the deposit known as "kettle-stone," "boiler-scale," etc.

Conversion of Hard into Soft Water.—Where no other water is available, it generally becomes necessary to render hard water soft before it is fit to be used. In cases where the alkaline-earth bases are present in the form of carbonates, simple boiling will be sufficient. As soon as the carbonic-acid gas is driven off by heat the lime and magnesia carbonates are precipitated, and the water is rendered soft. The same object will be accomplished by the addition of milk of lime in proper quantity. To determine how much of the precipitant must be employed to effect complete precipitation without leaving an excess of free lime in the water, the amount of hardness in each case must be previously ascertained. For convenience, the relative hardness of water is expressed in degrees, one degree corresponding to one part of lime in one hundred thousand parts of water.

It should be remembered, however, that boiling suffices to render hard water soft where the hardness is caused by the presence of the alkaline-earth carbonates. The chloride of calcium and the sulphate of lime, and the corresponding magnesia salts, remain in solution in the boiled water; neither will the employment of lime-water serve to precipitate these salts. To effect the complete separation of lime and magnesia under such conditions, it is necessary to add a suitable quantity of the carbonate of soda, by which all the lime and magnesia present is precipitated as carbonates, and an equivalent quantity of the corresponding salts of soda is formed, which remains in solution. The quantity of soda to be added will depend upon the degree of hardness. Water of ten to fifteen degrees of hardness may still be called soft, and is available for all purposes.

Consumption of Water in Cities.—In planning water-works, a careful estimate of the quantity of water that will be required is of the first importance, for by this the size and capacity of the works will be governed. Statistics exhibit wide variation in the consumption of water *per capita* in various countries, depending, apparently, upon climatic conditions, the available supply, and the habits of the people. Thus, the daily quantity per head for the population in Rio Janeiro is two gallons; in Edinburgh, eleven gallons; in Munich, seventeen and five-tenths gallons; in Paris, twenty gallons; in London, twenty-one gallons; in New York, one hundred and twenty-five gallons; in Rome, two hundred and seven gallons; etc. A daily supply of seventeen and five-tenths gallons per head may therefore be taken as a fair average. It may be remarked incidentally that the requirement is higher during the daytime than at night, and in summer than in winter. Of the total amount, it may be estimated that forty-three per cent. is used for drinking and domestic service, eighteen per cent. for manufacturing purposes, twenty-five per cent. for watering the streets, gardens, etc., four per cent. for public fountains, and ten per cent. for baths. This estimate is based on the conditions which obtain in Vienna.

Sources of Water-supply.—The water-supply of small towns is frequently obtained from wells. Owing, however, to constant contamination of the soil with excrement, and other sources of pollution, especially where composts are in vogue, in the course of time the water of wells fed by surface-drainage in such situations comes to be little else than diluted sewage, and, consequently, a prolific source of sickness and death. With the increase and concentration of population, this method of water-supply must be abandoned.

Spring-water.—Flowing springs, where they may be relied upon for a constant supply of water, may be hollowed out so as to provide a chamber of considerable area in which the water may accumulate, and from which it may be distributed in suitable pipes to the points of consumption. Where large bodies of water, such as inland lakes, are accessible, they afford very desirable sources of supply (Glasgow, Chicago). In India such bodies of water are extensively employed for this purpose.

River-water: Purification.—The rivers, however, afford the most common sources of supply, though their water is frequently very turbid and requires purification before being used. This is accomplished either by conducting it into large basins, where, after a short period of repose, the major portion of the suspended sediment subsides, or by some form of filtration, or by a combination of both these methods; or the purification may be effected by chemical means. Clearing in subsiding-reservoirs is the oldest method. For this purpose, as the water should stand a few days before drawing off, several sufficiently capacious basins, so contrived as to permit of periodical cleansing, are necessary. To facilitate this, such subsiding-basins are occasionally built in compartments, from any one of which the water may be withdrawn.

Filtration is the more expeditious and effective method of purification, as it suffices to remove not only the suspended mud and dirt, but also, to a notable extent, the organic impurities. For this purpose either natural or artificial filtration may be employed.

Natural Filtration is admissible in cases where deposits of sand or gravel free from clay and sufficiently deep occur adjacent to a river. It will then suffice to dig long trenches, extending below the level of the ground-water and from 50 to 150 feet distant from the river-bank, and to wall these trenches with masonry at the sides and top, leaving the joints open (*pl.* 52, *fig.* 11), or to lay in them perforated iron pipes. These pipes are then placed in suitable communication with underground conduits, and the trenches are then filled up. With this arrangement, no impurities can enter from the outside. The water filters through the gravel, enters, quite clear, through the open joints of the masonry or through the perforation of the iron pipes, and flows through the underground conduits founded for the purpose into properly-appointed storage-wells, from which it is further distributed by pumping-machinery (Dresden, Leipsic, Halle, Riga).

The Filter-beds for town and city supply usually comprise a stratum of sand several feet thick resting upon a heavier stratum of gravel and small stone, which latter are provided to sustain the sand and to afford channels through which the filtered water can run off. The principal portion of the impurities collect upon the upper surface of the layer of sand, and provision must therefore be made for cleansing this from time to time or for renewing it as may be found necessary. It is essential that the water should come to the filter-bed under some pressure, and it is desirable, where this is practicable, to permit the water to clear measurably in subsiding-basins before it is admitted to the filter-bed. In Figure 10 is shown a section of one of the filter-beds at Chelsea, near London, of which the largest is about 350 feet long by 175 feet wide. The floor is a stratum of impervious clay 1½ feet thick. The side-walls are 12 feet high. Along the floor of the filter-bed and parallel with one another are eleven pipes having loose joints, to permit the percolation of water into them. They are surrounded by a stratum of small stones; upon this is placed a layer of shells; then follows a layer of coarse sand 1 foot thick, and the uppermost layer, finally, is formed of 2 feet of fine sand. The turbid water percolates through these various strata successively, and finds its way into the open-jointed pipes above named, where the ends terminate in a collecting-pipe. Through the latter the filtered water is conducted to the reservoir, from which it is sent through the mains and service-pipes.

In the United States, neither filtration nor covered reservoirs are in use —except, perhaps, in isolated cases. In some instances, however, artificial aëration by one means or another is employed with beneficial results for preventing the development of aquatic vegetation, to which, during the hot weather, the water in open reservoirs is very susceptible. The objection urged against the adoption of the system of filtration so extensively practised in England is its cost. The subject of the purity of the water-supply is nevertheless attracting growing attention.

Artificial Filtration is more frequently resorted to, large watertight basins of masonry being founded for the purpose. Besides sand and gravel, sponge, coke, animal and wood charcoal, pumice-stone, pounded brick, carbide of iron, spongy iron, and many other materials, have been used for this purpose, but except fine sand there has yet been found no practically available material for filtration on a large scale.

Filters for Domestic Service.—Besides the filters designed for use on a large scale, there are smaller appliances for domestic service, manufactories, etc. The requisites of an effective filter of this class are that it shall free the water from mechanically-suspended impurities, and shall pass it constantly, automatically, and rapidly enough for practical purposes, and that with the least amount of labor it shall permit the ready and thorough cleansing of the filter-bed. The forms of such devices are legion. One, invented by Fonville for filtering the surface-water, is shown in Figure 9 (*pl.* 52). It consists of a wooden chamber divided by horizontal partitions of perforated wood, with three compartments. These compartments contain well-washed sponge, coarse river-sand, and vegetable charcoal, proceeding from above downward in the order given. The pipe at the right conducts the unfiltered water to the apparatus with the pressure of the service-mains; the pipe at the left conducts the filtered water away. The eight valves with which the filter is provided may be so adjusted as to exclude the water from any compartment or to cause the water to flow forward or backward in any of them; so that whenever the contents of any of the filtering compartments become clogged or require cleansing a brief reversal of the flow is generally sufficient to restore it to proper working-order. The charcoal requires renewal once a week.

In certain of these devices it is sought to effect the rapid removal of the very fine sediment by the use of such coagulating substances as alum, by which it is very thoroughly separated, and remains on the filter entangled in the flocculent alumina. The quantity of alum required to accomplish this object is extremely small. In some forms of the apparatus it is admitted in regulated quantities predetermined by the condition of the water and the capacity of the filter, and the quantity remaining undecomposed in the filtered water is so infinitesimal that it affects neither the taste nor the qualities of the water. In other forms the filtration, either simple or aided by chemical agencies as just described, is supplemented by artificial aëration, whereby the palatability and general wholesomeness of the water are notably improved.

Storage-reservoirs.—For the water-supply of large towns and cities there are usually provided elevated reservoirs whose principal object is to preserve the equilibrium between the water consumed and that supplied. The larger portion of the consumption takes place during the daytime, but even then it is not regular, while the influx of water from flowing springs or a gravity supply is constant during the twenty-four hours. Consequently, without reservoirs for storage, the portion of the water flowing in during the night would run to waste. Where the supply is pumped from rivers or lakes, the presence of a large reservoir in which a considerable volume of water may be stored is a safeguard in case of an accident to the pumping-machinery, for without this provision the stoppage of the pump would at once stop the supply. In large cities there are usually several pumping-stations; so that in the event of a break-down of one of the pumps communication between the disabled plant and its proper reservoir is shut off by closing a valve in the pumping-main, and connection is established between the reservoir and the pumps of another station.

Capacity and Classes of Reservoirs.—To be really serviceable, the capacity of these reservoirs should be very large; as a minimum, they should be capable of holding one-third of an entire day's supply. To facilitate their cleansing—which is periodically necessary—they should be separated into several compartments by suitable division-walls. Reservoirs may be classed, according to the manner of their location, (1) those whose water-level is below the surrounding ground-level, and (2) those whose water-level is elevated to a greater or less extent. The first are large substantial excavations with floor and walls of brick, masonry, or concrete. The second often require costly foundations and very strong retaining-walls, which are usually great embankments of earth. All such reservoirs should be covered, to keep the stored water clean and cool.

Stand-pipes.—Where circumstances are unfavorable to the construction of elevated reservoirs, recourse may be had to stand-pipes (*pl.* 52, *figs.* 18, 19). These consist of tall towers in whose tops are water-chambers (one in each tower) with which inflow and outflow communicate. The water is pumped into these elevated storage-chambers, and flows out of them into the service-pipes. These chambers serve as substitutes for the elevated reservoirs in furnishing the water-service with the constant pressure required to cause the water to rise to the upper stories of high buildings, in case of fire, etc. In the United States, the system of direct pumping into the mains by what is known as the Holly Direct Supply System is largely employed in the smaller cities and towns.

London Storage-basins.—To give an idea of the magnitude of the storage provision demanded for the water-supply of a great city, mention may be made of the reservoirs of London. The population supplied by the water companies of that city in 1887 was 5,274,542, and the average daily supply (in the month of May of that year) was 160,388,316 gallons. Of this, more than half, or 82,366,466 gallons, came from the Thames, and the balance from the river Lee, and from certain chalk-springs in the valleys of the Lee and Thames, and from twenty-one deep wells sunk into the chalk-formation to the north and south of London. There are fifty-four subsidiary reservoirs for unfiltered water, with an area of four hundred and sixty-five acres and an available capacity of 1,290,100,000 gallons, and fifty-three covered reservoirs for the storage of the water after filtration, with a capacity of 160,002,000 gallons. The number of filter-beds is ninety-nine, with an area of ninety-eight acres.

Water-distribution: Aqueducts.—In ancient times the stored and purified water was distributed by canals of masonry which were frequently carried through long tunnels and upon high aqueducts. In modern times works of this nature are not so common, pipes, which are more convenient, less costly, and more readily adapted to irregularities of the ground-surface, being almost exclusively used. (Compare *pl.* 52, *fig.* 20.)

Croton Aqueduct.—New York has at this time (1889) nearly completed a splendid aqueduct from the Croton River Valley to the city, a distance of thirty and three-quarter miles, of which twenty-five miles is cut through the solid rock. Figure 4 (*pl.* 54) is a view of the section of this aqueduct where it is taken beneath the Harlem River, in the form of an inverted siphon, the excavation being in the solid rock. Provision is being made by this improvement for supplying no less than 200,000,000 gallons of water daily—a quantity which will be ample to meet the growing requirement of the American metropolis for many years to come. The great reservoir at Quaker Dam, which will form an important adjunct to this new aqueduct, will have a storage capacity of 3,600,000,000 gallons of water.

Pipe Systems of Water-distribution.—Two systems of distributing water for the supply of towns or cities are in vogue—namely,the "ramification" system and the "circulating" system. In the ramification system, commonly employed, the supply passes from the principal main into tributary mains, from these again into the large branches, and thence, through still smaller branches, into the house service-pipes to the points of consumption. In the circulating system all the branches communicate at both ends with the principal main; so that the entire system of pipes may be regarded as an underground reservoir that may be tapped at any desired point. The advantage of the ramification system is that the mud in the water is carried along to its extreme end, and may there be discharged through suitable openings arranged for the purpose; the disadvantages are that the consumers located at a distance from the principal mains may have their supply sensibly diminished by the consumption of those nearer to the main supply, and that if a branch main be broken near the chief main all that section of the town receiving its supply through the affected branch will be deprived of water. In the circulating system, these objections are avoided, as the water will always find access to all parts of the system of connected pipes from two sides.

Pipe Aqueduct over the Wissahickon Valley, Philadelphia.—An interesting example of a pipe aqueduct is that designed by Frederick Graff, chief engineer of the Water Department of Philadelphia, and erected in 1870, for carrying the water from the Roxborough to the Mount Airy reservoir across the valley of the Wissahickon for the supply of Germantown, a suburb of Philadelphia, as shown in Figure 2. It is formed of two parallel lines of 20-inch cast-iron flanged pipes, which constitute the top members of a series of inverted bow-string trusses composed of short Phœnix posts $5\frac{3}{8}$ inches in diameter, resting on chains formed of long links, or eye-bars, having a sectional area of 10 square inches each. The ends of the chains are attached to lugs on top of the pipe at the ends of each span. The structure comprises four spans, each $165\frac{3}{4}$ feet long, the highest elevation of the centre of the pipes above the water of the creek being 100 feet. The three piers are each formed of a group of four 9-inch Phœnix columns, respectively 72, $97\frac{1}{2}$, and 48 feet in height, resting on low masonry foundations 7 by 14 feet in horizontal section.

Washington Combined Aqueduct and Bridge.—The ingenious artifice of utilizing a pipe line for the double purpose of conveying water and supporting a bridge structure is exhibited in the case of an aqueduct-bridge crossing the Rock Creek near Washington, D. C., over which the structure carries the waters of the Washington conduit. It was built in 1858 by Captain Meigs of the United States Engineers. For this purpose he used two arched ribs formed of water-pipes of circular section (*pl.* 54, *fig.* 3), through which the water flows. The span of the bridge is 200 feet, the rise is 20 feet, and the width over all 28 feet. The pipes are 4 feet in diameter and $1\frac{1}{2}$ inches thick. The pipes are not cast to the curve of the arch, but are in straight lengths of 12 feet, with flanged joints whose faces are parallel with the corresponding radii of the arch. At the skewbacks the ends of the pipes are faced to large conical boxes, admitting the water, and resting on the masonry. The roadway is of timber supported on spandrils formed of rolled wrought-iron beams. The pipes were at one time jacketed inside with staves of resinous pine, 3 inches thick, to prevent the freezing of the water; but this prevention was found to be unnecessary, and the lining has since been removed.

Distributing-pipes.—The material universally employed for distributing-pipes is cast iron, as from it they are easily and cheaply manufactured, while at the same time they possess the requisite strength and admit of the easy attachment of branch-pipes. The jointing of these pipes is effected in several ways. The so-called "flange-joint" (*pl.* 52, *fig.* 14) was formerly much employed. In this the ends of the pipe were flanged, a disc of leather or of lead was laid between the two flat surfaces, and the ends were firmly united by means of bolts and nuts. This form of joint, which has been found not sufficiently flexible, has been superseded largely by the socket-joint. In the method now in common use one end of the pipe is cast with a bell-shape enlargement, into which the plain end of the next pipe is inserted. The space between the two, which is about equal to the thickness of the pipe-walls, is filled for about half its length with tarred hemp well rammed in, and the remaining space is filled by running lead into it. At certain intervals simple butt-joints are made with the use of a surrounding collar which serves to permit the removal of the sections when repairs are necessary. To allow for alteration in length of the line in consequence of changes of temperature, certain compensating sections are introduced into the same (*fig.* 15). Where a line of pipe must be carried across a river (*pl.* 54, *fig.* 1), or, in other cases, where it must rest upon a curved or irregular bottom, the joints must be given sufficient flexibility to adapt themselves to the curvature. In such cases ball-and-socket (*pl.* 53, *fig.* 9) or knee joints, etc., are substituted for the usual forms of connection.

Pipe-valves.—For emptying a system of water-mains, as well as for removing the accumulated sediment, discharge-pipes controlled by valves are placed at the lowest points of the line. At the highest points the air may collect in such volume as to prevent the flow of water, on which account it is necessary to provide suitable vents through which it may escape. Figure 16 (*pl.* 52) shows a form of air-valve consisting of a vertical chamber in which a float automatically closes and opens a valve in its upper portion as the level of the water rises and falls. For controlling the flow in the various branches of the system, shut-off valves are provided at the proper places. A valve of this description is shown in Figure 17.

Other Forms of Pipes.—Before the period of cast-iron pipes, wooden pipes from 10 to 12 feet in length were employed, and are still occasionally used; in many situations they have shown an extraordinary durability. Figure 12 exhibits a wooden water-pipe, partly in section to show one method of joining the parts with the aid of iron collars of double conical form sharpened on each side. Water-pipes of stone-ware or terra-cotta, usually from 6 to 8 feet in length, are likewise in use. Figure 13 shows a section of this kind of pipe, whose differently-formed ends clearly explain the mode of joining section to section. The joint-packing in this case consists of hydraulic cement, and water-pipes formed of this material have been found to answer well the purpose for which they are designed. Leaden pipes, which are of small calibre, are used only for making house-connections from the street-mains. Tin-lined lead pipes are somewhat in vogue in localities where lead-poisoning is feared. In a number of American cities house-service pipes of galvanized (cast) iron are used to a considerable extent, and apparently with satisfactory results.

V. TELEGRAPHS AND TELEPHONES.

Classes of Telegraphic Systems.—The transmission of intelligence telegraphically may be accomplished either by means of optical or acoustical signals direct from station to station; or some other communicating media, such as air- or water-columns, electric conductors of wire, etc., are indirectly used to produce signals between the despatching and receiving stations. Optical and acoustical telegraphs still find a limited application in the operation of railways (see page 179), for military and engineering uses, and for signalling at sea. Pneumatic telegraphs are to some extent in vogue for domestic service (the pneumatic bell). Hydraulic telegraphs, on the contrary, have not as yet passed beyond the experimental stage. All these systems, however, have been forced into the background by the electric telegraph and the telephone, which are to-day substantially the only methods in general use for transmitting intelligence to a distance.

First Electric-telegraph Systems.—Although the idea had been broached much earlier, yet the first efforts to apply practically the wonderful speed of transmission possessed by electricity for telegraphic purposes appear to have been made by Le Sage of Geneva, who in 1774 constructed a telegraph-line formed of twenty-four insulated wires to the end of each of which was hung a pair of pith balls. When the opposite end of any of these wires was brought in contact with the prime conductor of an electrical machine, the balls forming the corresponding pair were electrified and repelled each other. It was possible by this means to signal each and any of the twenty-four letters constituting the French alphabet. Somewhat later Lomond improved upon the method of Le Sage by dispensing with all but a single wire and a single pair of pith balls, and designating the desired letter by the amount of divergence of the balls. Following these primitive efforts, Reiser, Böckmann, and Salva attempted to devise a signalling system based on the employment of electric sparks transmitted in a certain predetermined manner as to time and number. An apparatus by Salva operating on this principle was shown in Madrid in 1798. Modifications of this plan were experimented with by Cavallo (1797) and Ronalds (1816), but led to no useful result. All these attempts were restricted necessarily to the then only known means of generating electricity—namely, by friction. They all proved impracticable and unavailing, for the reason that the static electricity produced by the frictional-electric machine is of such excessively high pressure, or potential, that it is impossible to confine it by insulation to wires and to prevent it from passing off to neighboring bodies.

The Voltaic Pile,[1] discovered in 1800, opened the way for a practicable system of electric telegraphy. The electrical current developed by the voltaic battery has sufficient strength to follow the longest and most circuitous course through metallic conductors (wires), and, on the other hand, its pressure is so low that it may be confined readily to the wires by the application of suitable insulating devices or coverings.

Sömmering's System.—Sömmering of Munich (1808) endeavored to make use of the property of the voltaic battery to decompose water as the basis of a system of telegraphy. In Sömmering's system "thirty-five glass tubes closed at one end and filled with water were inverted over a similar number of gilded metallic strips which passed through the bottom of a long and narrow glass trough or reservoir of water. This constituted the receiving apparatus. . . . . Each of the tubes corresponded to some letter or numeral and was joined to the transmitting station by a separate wire soldered to the metallic strip underneath. The wires were insulated from one another, and after leaving the reservoir were bound into a single strand. At the sending station each wire was separately insulated and connected with a metallic terminal. To send a signal, it was only necessary to bring the two poles of a voltaic pile to two of the terminals in question. The current, passing from one terminal, traversed its line wire to the voltameter at the receiving station, where it passed between the gilded

[1] Named in honor of its discoverer, Alexander Volta.—ED.

metallic strips corresponding to the terminals touched by the poles, and returned through the line wire to the terminal of the other pole of the pile. When this was done, bubbles of hydrogen appeared at the metallic strip in communication with the negative pole, and bubbles of oxygen at the other one. Thus two signals were given simultaneously, of which the hydrogen took precedence. When it was desired to indicate only one letter, the positive pole of the battery was brought in connection with zero and the negative pole with the letter to be transmitted. Sömmering proposed to call the attention of the receiving station by liberating an alarm by means of the accumulated gas" (Prescott). The method of Sömmering proved too expensive and too slow to be of any commercial value, and in consequence was never applied in practice. Only of late years has the chemical effect of the voltaic battery received practical application in the chemical telegraph of Bain. (See p. 353.)

Electro-magnetic Needle Telegraphs.—The discovery of electro-magnetism by Oersted of Copenhagen in 1820 may be said to mark the date of the origin of the electric telegraph. The invention by Schweigger of the "multiplier" was an important contribution to its practical solution, since by its use there was obtained the power of causing the deflection of a magnetic needle by even the feeblest current. The earliest attempts to produce an electro-magnetic telegraph are to be credited to Ampère in Paris (1820), Ritchie in London, and Schilling of Cronstadt in St. Petersburg (1832). It was not, however, until 1833 that Gauss and Weber of Göttingen succeeded in introducing the first practical telegraph of this kind. These *savans* erected a line of telegraph between the physical cabinet and the observatory of the university in Göttingen.

Gauss and Weber System.—The transmitting apparatus in the Gauss and Weber system was a magnetic needle enclosed in a coil of wire, and the currents were produced by a magneto-electric inductor. The receiving apparatus (*pl.* 58, *fig.* 1) was a large coil, or "multiplier," of insulated copper wire, the ends of which were connected with the line wires. Within the multiplier was suspended by a fibre of silk a permanent magnet, to whose spindle a long mirror was attached in such a manner that it would throw into the axis of a telescope suitably mounted at a distance of 10 or 12 feet the reflected image of a horizontally-divided scale. A system of right- and left-hand deflections of greater or less amplitude on the narrow scale constituted the alphabet. The movements of the inductor at the transmitting station caused the transmission of currents through the line wire, which affected the magnetic needle within the multiplier and became manifest by slight movements of the magnet. These slight movements were greatly multiplied by the action of the mirror and the telescope. An apparatus similar to this in principle is used at the present time in submarine-cable telegraphy. (See p. 351.)

Steinheil's System.—Steinheil of Munich substantially improved the magneto-electric telegraph of Gauss and Weber, both in the construction of the induction apparatus for generating the magneto-electric currents and in the receiving apparatus. The latter (*pl.* 58, *fig.* 3) was composed of two needles or bars within a multiplier and having their free adjacent ends prolonged to terminate in a species of pen, which imprinted a series of dots upon the surface of a strip of paper that was caused to travel past them. To Steinheil also is accorded the credit of having made the very important discovery that the second, or return, wire of a telegraphic circuit was unnecessary, and that by simply grounding the wires at the terminal station the return current would pass through the earth. While Gauss and Weber, and Steinheil, employed the magneto-electric current in their telegraphs, Wheatstone and Cooke in England returned to the use of the voltaic current, which is better adapted to the purpose, and in 1837 the latter patented certain improvements upon Steinheil's needle telegraph.

First Morse Telegraph.—In 1835, Morse in the United States constructed the first crude working model of his well-known electro-magnetic telegraph (*fig.* 4), which embodied the following parts—namely, "a single circuit of conductors from some suitable generator of electricity; a system of signs, consisting of dots or points, and spaces to represent numerals; a method of causing the electricity to mark or imprint these signs upon a strip or ribbon of paper by the mechanical action of an electro-magnet operating upon the paper by means of a lever armed at one end with a pen or pencil; and a method of moving the paper ribbon at a uniform rate, by means of clock-work, to receive the characters." Figure 7 represents the modified form of the register or recording instrument used by Morse on the first experimental line between Washington and Baltimore, opened on the 27th of May, 1844. The arrangement of the circuits is shown in Figure 5. Figure 8 exhibits a register of more modern design, embodying, however, the same elements of construction.

Relays.—Of much importance at this stage of the art was the introduction by Wheatstone of the so-called "relays," by which the line current is relieved of the work of making the signs that constitute the message, but is caused to generate strong local currents which are employed to actuate the recording mechanism. The relay is shown in Figure 34 (*pl.* 57). Its object is to call into action the power of a local battery by which the work of recording is performed. This is necessary for the reason that the circuit current is too feeble to do more than establish a communication with the local battery. It consists, as will be observed by an inspection of the Figure, of an electro-magnet, M, M, whose light iron armature is attached to the pivoted lever, B, B′. The back end of the lever is drawn down by the spring, *f*, and the armature by this means is separated from the magnet poles, M, M. The front end of the lever rests either against the insulating ivory point of the thumb-screw, D, or against the conducting steel point of the screw, D′, according as the current entering through the wire conductor, *m*, passing through the coils of the electro-magnet, M, M, and then to the earth, causes the armature, A, to be attracted to the poles of the magnet, or, as the current ceases to flow, the retractile power of the spring, *f*, comes into play. The brass standards, E, C, S, are insulated from the base board, P, P′. L, K is the local battery which is thrown in or out of circuit by the relay. R is the receiving instrument. It will be apparent from the foregoing description that when the main, or primary, circuit energizes the magnet, MM, and causes its armature to be attracted, thus making contact between B and D′, the local battery will be closed, its current proceeding from K to the receiving instrument, and from this back to the battery. The relay employed on the closed-circuit lines differs from that of the open-circuit line just described simply in the reversed arrangement of the points B, B′. (Comp. *pl.* 57, *fig.* 35.) At present the source of the electric current almost universally employed in telegraphy is a voltaic battery.

The Batteries in most general use for telegraphic purposes are the following: the Meidinger cell, composed of zinc and copper elements in a cell without porous cup, the two liquids constituting the electrolyte being kept apart simply by the difference of their specific gravities (the liquids employed are solutions of sulphate of copper and sulphate of magnesia, a reserve supply of crystals of sulphate of copper being provided in some convenient manner, so as to make good the consumption of this salt by the action of the battery); the Marié-Davy cell, composed of zinc-carbon elements, in which the carbon is immersed in a paste of moistened sulphate of mercury and the zinc in pure water; the Leclanché cell, of zinc-carbon elements, in which the carbon plate is placed in a porous cup filled up with fragments of peroxide of manganese and carbon and the zinc occupies the outer vessel, and in which a diluted solution of sal-ammoniac constitutes the electrolyte. The qualities sought for in a battery are that it shall furnish a current of great constancy and shall require the least possible attention for cleansing.

The Siemens Armature, a device well known to electrical engineers, is of peculiar construction (*fig.* 28). It is channelled longitudinally with two deep, broad grooves on opposite sides, within which is wound, also longitudinally, a coil of fine insulated wire. The armature is supported on pivots above and below by the brass caps, F, F, and is rotated by means of the pinion on its upper extremity, which gears into a toothed wheel turned by the handle, H. The numerical relation between the teeth of the wheel and pinion is such that one revolution of the wheel causes the pinion to revolve thirteen times, reversing the magnetism along the whole length on each side of the armature, and thereby inducing in the coil, when the circuit is closed, thirteen positive and thirteen negative electrical pulsations of equal and opposite magnetic effect. When the coil is turned half round on its vertical axis, the polarity of the armature is also changed and a magneto-electric current induced in the armature coil in one direction, and on turning it half a revolution farther round, so that it takes up its former position, a current in the opposite direction is induced. The ends of the coil of wire which are attached to the brass caps are connected, one (s') to the earth-plate, and the other (s) to the coils of the electro-magnet of the indicator, and thence to the line. The pointer of the indicator at the receiving station repeats the message sent from the transmitting station letter by letter. Siemens has lately replaced the permanent steel magnets by electro-magnets. The residual magnetism in the electro-magnets is found to be sufficient to produce a current in the armature by induction. This induced current of the armature in turn excites the electro-magnets, these in turn induce a still stronger current in the armature, and so on until the point of magnetic saturation is reached.

Circuits.—For the transmission of signals in the case of telegraphs operated with batteries, two arrangements of the line may be employed, which are known respectively as the "open-circuit" and the "closed-circuit" plan. In the open-circuit plan the batteries at both ends of the line are open when the line is not in use, but are both closed whenever the key of either station is depressed. Thus the instruments at both stations are operated when either one or both keys are depressed. In the closed-circuit plan, the circuit is closed and the current flows through the line when the latter is not in use. The transmission of signals, however, by this plan may be effected in two ways. In the Morse system, as operated in the United States, the keys at each station are provided with what is known as a "circuit-closer," and the connection remains unbroken so long as neither station is transmitting. To send a message, the operator opens a switch of his key, thus interrupting the flow of the current. By operating his key the characters of the Morse alphabet are received at the other station. By this plan of arranging the instruments of a line the transmission is effected by closing the circuit through the key. In a modified form of the closed-circuit system in use in Germany upon the railway-lines, the signals are directly transmitted by breaking instead of closing the circuit.

The Keys used to make and break the circuit are shown in Figures 32 and 33 (*pl.* 57). Figure 32 represents a key for an open-circuit line in which, when the line is not in use, a contact is maintained between *c* and *c'*, through which a current may be received or may pass through some other station. By depressing the lever, however, the local battery is closed through the contact, *b*. The closed-circuit key (*fig.* 33) is provided only with the contacts *d* and *u*, through which the circuit is closed when the line is not used for transmission. The circuit is broken by depressing the lever. The Morse key (*pl.* 58, *fig.* 6), as employed in the United States with the circuit-closer or switch, is usually open. When the switch is open, the circuit is completed through the key by pressing upon the button of the lever, by which a platinum stud on its under side is brought in contact with a similar stud in the centre of an anvil. When the pressure of the finger is removed, a spring beneath the lever throws it up to its normal position, thus breaking the circuit.

The Plug Commutator is extensively used on lines operated by Morse instruments, with some modifications. Figure 40 (*pl.* 57) shows the plug commutator of Siemens and Halske. It consists of three heavy pieces of brass separated from one another upon the insulated base and furnished with holes, D, C, 1, and 2. L1 and L2 are the line wires from adjacent stations. T is the key; R, the relay; S, the registering instrument; LB, the line battery; OB, the local battery; and G, the galvanometer which indicates the existence of a current in the line. The switch itself is distinguished by the letter U. By inserting a metallic plug in hole D the station is cut out and L1 and L2 are connected. The current then passes from L1 over U (D) to L2. If the plug be inserted in C, the station will receive any message sent through. In this case the current from a station on the left will pass over L1, G, T1, 2, R, U, L2, etc. If now the key T1 be depressed, the station is placed in working communication with all stations on the line. In this case the current passes in the direction L1, G, T1, 3, Z, (LB), K, L2. In like manner the holes 1 and 2 serve for the insertion of the plug when the station wishes to communicate with the way station on the right or left respectively, or to receive communications from these way stations.

Telegraph Alarms.—A telegraph station is not complete unless provided with alarms (*pl.* 57, *figs.* 25, 27). Figure 41 exhibits a call-bell in which the armature, *c*, carrying the hammer, *k*, is drawn back by the spring at *c*, when the current ceases to flow round the coils of the electro-magnet, *M*, *M*, and is pressed against the contact-spring, *r*, when the current is re-established, by which the armature will be attracted, and the bell struck by the hammer. By this artifice a rapid making and breaking of the circuit is effected, and a corresponding intermittent sounding of the bell. When a system of this kind is used as an annunciator, for example, in a hotel, the rooms from which the circuit must be closed and broken must be furnished with a push-button (*fig.* 42). Communication is established by pressing upon the button. In the bell-signals for railway use the current is utilized merely to release a train of clockwork, which by simple mechanical means rings the bell. Siemens and Halske's railway signal-bell operating on this principle is shown in Figure 43.

Classes of Telegraphs: Needle Telegraph.—According to the method of signalling employed, telegraphs are distinguished as needle, dial, printing, and copying telegraphs. The needle telegraph is made to convey signals by the deflection of a magnetic needle through the medium of an electric current caused to flow through a coil of insulated copper wire within which it is suspended.

Wheatstone and Cooke's Needle Telegraph.—Figures 22 and 23 exhibit, respectively, front and rear views of the simple needle telegraph of Wheatstone and Cooke. *A* (*fig.* 23) is the multiplier surrounding the needle, and consisting of a coil of fine silk-covered copper wire wound round a thin frame of brass. An exterior needle (*fig.* 22) which serves as the indicator for communicating the signals is carried on the same axis as the needle of the multiplier; to neutralize the influence of the earth's magnetism, the poles of the two needles, however, are placed in reverse position relative to each other. Figure 24 is a diagram exhibiting two stations connected by this system of communication. *G*, *G′* are the signal-key handles; *N*, *N′*, the multipliers; *g*, *g′*, the line wire. The key-handle *G*, projecting from the exterior of the enclosing frame, is mounted on the same axis with a disc of wood in the interior, upon the periphery of which are placed seven conducting pieces of brass separated from one another by interposed strips of ivory (*pl.* 57, *fig.* 24, *a–g*). Certain of these brass pieces are connected with one another by strips of brass—for example, *a* with *b* and *c*, *f* with *d*, *e* with *g*. Four contact springs, *x*, *y*, *m*, and *n*, press against the edge of the disc, of which the first two are connected with the poles of the battery, *m* with the ground plate, and *n* with one terminal of the multiplier. When the two handles, *G* and *G′*, are placed vertically, the batteries are cut out from the line. When the handle *G′* is placed to the right, as shown in the Figure, the current passes from + to — pole in one direction. Turning the handle to the opposite side sends the current in the opposite direction through the apparatus, and consequently produces a deflection of the needles to the opposite side. The alphabet is formed from various predetermined combinations of the needle deflections.

Thomson's Cable Telegraph.—The needle telegraph was employed in working the submarine line between Ireland and America, Professor (now Sir William) Thomson having devised an apparatus for the purpose corresponding in principle with the reflecting, or mirror, galvanometer used by Gauss and Weber in 1833 (p. 346). It consists of a slender bar of steel suspended from a cocoon-thread and carrying at its point of suspension a very delicate mirror. The needle passes within a coil of fine copper wire. At the distance of about 3 feet a lamp contained within a sheet-metal box throws upon the mirror a slender beam of light through a slot, provided for the purpose, in the box. The mirror reflects this beam upon the graduated scale. Any deflection of the needle, however slight, in consequence of the passage of the current through the line, is thereupon reproduced and greatly magnified by the movement of the band of light on the scale. Figure 2 (*pl.* 58) represents the appearance and operation of the ingenious siphon recorder devised by Sir William Thomson, and designed actually to delineate on paper the irregular movements of the reflecting galvanometer above referred to.

Double-needle Telegraphs, which are nothing more than a combination of two needle telegraphs of the kind just described, afford greater facility in the transmission of signals, but require two line wires, and are now but rarely used.

Dial Telegraphs.—For the utilization of magneto-electric currents, the several forms of the "dial telegraphs"—so called to distinguish them from the above-described needle telegraphs operated by currents of similar origin—are found very serviceable. In this modification an index, by suitable mechanical appliances, is made to revolve over a set of letters or other symbols placed around the circumference of a dial. By other appropriate means this pointer is caused to stop opposite any desired character, and thus a message is spelled out letter by letter.

The Siemens Dial Telegraph (*pl.* 57, *figs.* 27–30), one of the most convenient and valuable of its class, has been in use for many years on the government telegraph-lines of several European countries (Russia, Bavaria), and on the municipal lines of some of the principal European cities. The following description of this system, abridged from Prescott, explains its construction and operation. It consists of a battery of permanent magnets, between the poles of which revolves a coil of insulated wire wound upon a soft-iron armature. This coil develops alternate positive and negative currents, which traverse the line and pass through the coils of an electro-magnet at the receiving station, causing its armature to vibrate, an escape-wheel and a pointer. Figure 28 (*pl.* 57) shows this apparatus with its wooden case removed. In operating, the handle, H, is turned from letter to letter, these being marked on a horizontal dial-plate, J, stopping always against the tooth opposite the letter to be indicated. The metallic dial-plate, J, having ratchet-shaped teeth, *i*, upon its rim, is fixed upon the top of the compound magnet, which is formed of a number of permanent magnets, G, G′, screwed to an upright soft-iron plate. Between the poles of this system of permanent magnets is placed a cylinder of soft iron, E, E, which serves as an armature. The interior of the indicator is shown in perspective in Figure 29. The call-bell or alarm used with this instrument is seen at the top of the case in Figure 27. In Figure 25, which is one of Wheatstone and Cooke's dial telegraphs, A represents the key of the instrument in the despatching station, and B the indicating apparatus at the receiving station.

The Dial Telegraph of Bréguet, for many years in use with satisfactory results on the French railways, is an apparatus operated on the same principle as that of Wheatstone and Cooke, but embodies a number of substantial improvements. Figure 26 is a diagram of the connections of the dial telegraph devised by Siemens and Halske. In this apparatus, an important condition in the operation of this system will be the exact synchronism of the ratchet-wheels at the two stations. To save the cost of batteries, the dial telegraph is commonly operated with the aid of the magneto-electric apparatus of Siemens and Halske referred to above.

Printing Telegraphs: Morse System.—Of the printing telegraphs, that of Morse is the most widely used. Figure 31 (*pl.* 57) shows one of the forms of the Morse register. An armature, *o*, over the poles of the electro-magnet, E, E, is attached to one extremity of a lever, *nn′*, pivoted on a fulcrum near its centre. The other end of the lever carries a steel point which at each depression of the armature, *o*, presses upon a ribbon of paper introduced between the rollers, W, W′. (This ribbon is omitted in the illustration for the purpose of clearness.) The style will remain in contact with the paper ribbon as long as the armature is held down, and will be withdrawn from it by the action of the retracting spring, *h*, whenever the armature is freed from the attraction of the electro-magnet by the breaking of the circuit. There is thus formed a series of dots and dashes, the latter being produced by a more prolonged contact of the style with the paper; and these characters, in certain arbitrary combinations, constitute the telegraphic alphabet. For moving the rollers, W, W′, which guide the paper ribbon, either a spring or a train of wheel-work actuated by a weight, as shown, may be employed. For sending the Morse characters the keys (*pl.* 57, *figs.* 32, 33) are employed. The relay (*fig.* 34) serves to throw into the circuit the current of a strong local battery by which the signals are recorded.

Figures 37 and 38 exhibit the mode of arranging a line of telegraphic communication between two terminal and two intermediate stations, with the Morse instrument as the chemical printer. The letters *o*, *c*, *o*, *c* are the open-circuit keys (compare *fig.* 32); *b*, *b*, the batteries; and A, C, D, B, the electro-magnets of the recording apparatus. In Figure 37 all the keys are seen to be in contact with the parts *o*, but no current passes, because the circuit is broken at the points *c*, *c*. If, now, station D wishes to speak, the key of this station is pressed down on *c*, and the D-battery is thus closed. All the Morse instruments included in the main line, except that at D itself, will now receive the current, which will travel in the course indicated by the arrows, while at the same time their local batteries will not be called into action. Various other arrangements of line are in use, some operated upon the open-circuit and others upon the closed-circuit plan (see p. 349), for details of which the reader should consult special treatises on the electric telegraph.

Bain System.—In place of the style used for recording the characters as just described, Bain (1847–1848) employed electro-chemical decomposition. By this plan the record appears as a series of colored marks upon the paper. To this end, he passes the paper ribbon on which the record is to be made through a trough containing a solution formed of water six parts, sulphuric acid one part, and two parts of a saturated solution of yellow prussiate of potash. In this mode of recording, no pressure of the style upon the paper is necessary, and the relay may be dispensed with. The chemical telegraph also may be worked more rapidly than the usual method of printing. On the other hand, the dry writer has the advantage of greater reliability and cleanliness, the message being free from the risk of blotting or of being entirely missing in places, owing to the accidental absence of solution. In Figure 36 is shown a dry writer in which a small printing wheel carried on the extremity of the lever, *b*, and dipping and constantly revolving beneath the surface of the solution in the color trough, *c*, presses against the paper ribbon when the armature of the electro-magnet is attached.

Stöhrer's Apparatus.—To reduce the number of signals, and especially to lessen the time required to transmit the Morse signals, Stöhrer of Leipsic devised a double-style apparatus on the Morse principle, the register being furnished with two electro-magnets actuating separate writing-levers, making two rows of dots and dashes, but recording on the same paper ribbon. By this arrangement he was enabled to employ four elementary signals instead of two in constructing the alphabet. Stöhrer's apparatus has been used to some extent in Bavaria, but its advantages have not been found to be so decided as to cause its general adoption.

Type-printing Telegraphs.—The problem of transmitting, not signs, but the ordinary letters of the alphabet, so that the messages should be received in print, received the attention of the earliest telegraphic inventors. The first suggestion of a type-printing apparatus originated as early as 1837 with Alfred Vail, an associate of Morse, but, believing that the method could not compete successfully with the ordinary Morse system of transmission, his instrument was never perfected. Wheatstone next essayed the solution of the problem, without reaching a successful issue, although he constructed a working model which was operated before the Royal Polytechnic Institute in London in 1841.

House's Apparatus.—The first type-printing instrument sufficiently practical to come into considerable use was that of House, an American electrician, who in 1847 successfully transmitted printed messages over an experimental line between Cincinnati and Jeffersonville, a distance of one hundred and fifty miles. In 1849 this instrument, which was afterward greatly improved, was adopted commercially on a line between New York and Philadelphia, and thereafter came into general use.

Hughes's Apparatus.—The House apparatus has, however, been superseded by the type-printing telegraph of Hughes, another American electrician, which was brought out in 1855, and, as subsequently improved by his associate, Phelps, it has been adopted extensively throughout Europe and America.

Construction of Type-Printing Telegraphs.—The mechanical construction of these devices is too complex to warrant a detailed description. It must suffice to say that the type-printing instruments are operated by two methods. In one a type wheel is revolved by a step-by-step movement which is effected either by clockwork controlled by an electro-magnetic escapement or by the vibrating armature directly. In this class of type-writing instruments the printing is done either by a clockwork mechanism or by the direct action of an electro-magnet. To this class belong the instruments of Wheatstone, House, Bréguet, Dujardin, and the stock- and market-reporting instruments in general use. The "Universal Stock Printer" (*pl.* 58, *fig.* 9) is a typical form of this telegraph. The other type-printing instruments have for their essential principle the synchronous movement of the transmitting and receiving apparatus at two or more stations, and the printing is effected without arresting the synchronous motion of the type wheel. The motion of the type wheel of one station and of the transmitting mechanism of the other is regulated by two separate sets of mechanism, which keep exact time with each other. To this class belong the instruments of Hughes, Farmer, Phelps, and others.

Fac-simile Transmission Telegraphs.—The clever idea of reproducing at a distant station exact copies of writing, drawings, diagrams, charts, etc., telegraphically was first made practicable by Bakewell in 1847. Methods of fac-simile transmission have also been devised by Bain, Morse, Whitehouse, Gintl, Stöhrer, Cowper, Robertson, Delany, and others.

The Pan-telegraph of Caselli, which belongs in this class, is exhibited partially in Figure 39 (*pl.* 57). Its operation will be understood from the following brief account condensed from Prescott. Two instruments similar to that shown in Figure 39 (*pl.* 57) are employed, one at the transmitting and one at the receiving station. The actuating mechanism of this system is a heavy pendulum of iron swinging between two electro-magnets which become alternately magnetic by the action of a local battery, whose circuit is closed through these by the action of a second pendulum. The alternate action of the electro-magnets keeps the first pendulum in motion, and through this the remainder of the mechanism. At the right side of the frame are placed two covered metallic tablets, one of which, X, is shown in the Figure. Upon this is placed the original drawing, etc., to be transmitted at the sending station, or the prepared paper if at the receiving station, and, each instrument having two of these tablets, it is possible to transmit and receive a message at the same time. The two tablets are exactly alike, and it will be necessary in this account to refer to only one of them. Above the tablet X a frame, *p*, *q*, is mounted upon a vertical lever, A, B, which turns upon its centre on a horizontal axis. The connecting-rod, Z, is jointed to the lower end, B, of the lever, and to the rod of the pendulum. Thus the swinging of the pendulum-rod causes the frame, *p*, *q*, to move to and fro over the convex surface of the tablet X. The adjustable counterpoise, K, K′, serves to balance the weight of the frame, *p*, *q*, upon the centre of motion of the lever, A, B, which is coincident with the axis of the cylinder of which X is a segment.

The frame, *p*, *q*, carries a shaft provided with two screw-threads, *v*, *v′*, each being clasped by a nut to which is attached a clamp, *a*. At each complete revolution of the shaft the clamps move laterally the distance of one turn of the screw-thread. The revolution of the screw is so effected by an escape-wheel that the clamp, *a*, is moved laterally one-eighth of a millimetre at each oscillation of the lever, A, B. If a style be fixed in the clamp, *a*, so as to press by its elasticity against the surface of a sheet of paper laid upon the tablet X, and to leave a mark upon it, it is evident that by the oscillation of the frame, *p*, *q*, and the lateral motion at right angles caused by the screw, *vv′*, the whole surface of the sheet would be covered with parallel-ruled lines one-eighth of a millimetre apart. The apparatus, however, is so arranged that the style is lifted from the paper while passing in one direction over the tablet X, and in like manner upon the other tablet while passing in the opposite direction. The synchronism of the corresponding instruments is effected by a pendulum, a description of whose action will be unnecessary.

Operation of Caselli's Apparatus.—The manner in which messages are transmitted and received by Caselli's apparatus will now be understood from the following: At the sending station the message or any drawing or diagram to be transmitted is written in bold lines with ordinary ink on "silver paper," so called, which is prepared expressly for the purpose by coating the surface with tin. This is fastened by clips upon the surface of the tablet X, and through the clips the metallic surface is in connection with the negative pole of a main battery and with the earth, while the positive pole of the battery is attached to the clamp, *a*, and to the line. When the pendulum at the sending station is set in motion, the clamp and the style attached thereto begin to traverse the entire surface of the metallic paper. As long as the style is in contact with the metallic surface the main battery current is shunted through a short circuit; but whenever this contact is broken by the style passing over the insulating writing, its current passes through the line and through the clamp, *a*, at the receiving station, and finally to the earth. The clamp holds an iron-wire style which traverses a sheet of paper laid on the tablet X, the paper being prepared by treating it with a solution of yellow prussiate of potash acidified by sulphuric acid.

As the pendulums at both receiving and sending stations swing in exact time with each other, it is manifest that when the style at the sending station passes over a line of the non-conducting writing a corresponding blue line will be drawn upon the chemical paper at the receiving station. After half an oscillation of the pendulum has been completed, the styles are moved laterally one-eighth of a millimetre, but, as the clamp and the style are lifted from the paper during the last half-oscillation of the pendulum, this portion of time occupied in its motion is lost, but may nevertheless be utilized for sending another message, in the opposite direction, by means of the duplicate portion of the apparatus. After a complete oscillation, the styles at both stations will have moved laterally one-eighth of a millimetre. During the first half of the second oscillation there will appear upon the paper at the receiving station a second series of blue lines exactly parallel to the first and one-eighth of a millimetre distant from them. In this way the two instruments continue to operate until the style at the sending station has gone over the whole surface of the metallic paper, and that at the receiving station has produced in parallel-ruled lines a copy of the despatch written upon the metallic paper. The Caselli system has been put in practical use, but to only a small extent. The objection made to it and to others devised for the same purpose is that they are very slow in operation.

To avoid the necessity of providing intermediate stations with two sets of apparatus, one to communicate in each direction, and also to avoid repeating at each of the intermediate stations a message sent from one terminal station to the other, which would involve serious loss of time and multiply the chances of error in transmission, various arrangements have been devised by which communication may be established between any two stations included in the line. The pan-telegraph was opened for public use on the Paris-Lyons Railway in 1865.

Telegraph Lines: Overhead Wires and Supports.—The metallic conductors which serve for the transmission of the current consist usually of iron wire of suitable gauge, which it is the practice to galvanize to protect against rusting. At the terminal stations these wires are soldered to copper plates having about 10 square feet of surface, which are sunk in the earth. For supporting the line wires on overground lines, wooden posts are used, from 25 to 30 feet long, on which the wires are strung upon cross-braces from insulators. These posts are occasionally treated with antiseptic substances, as described on page 193. Their distance apart is, as a rule, 175 feet, corresponding to about thirty posts to the mile. Sometimes posts of iron are substituted for those of wood.

Insulators.—An important factor in the serviceableness of a telegraph-line is the insulation of the conductors from the posts. The wires are therefore supported by insulators of various forms, constructed usually of porcelain or glass. In Chauvin's insulator (*pl.* 57, *figs.* 45, 46), an inner bell, which forms the insulator proper, is kept dry by the outer one. The wire is laid in the notch, *a*, and is held in position by a thin wire wound round the groove in the neck. Figure 44 shows another form, composed of an iron shield in which is cemented a porcelain capsule, forming the insulator proper, from which depends a hook to which the line wire is attached. In the United States the use of glass insulators still prevails to a considerable extent, but they are inferior to porcelain. The Brooks insulator, a much superior instrument, has, however, come into very general use. It is formed of an inverted cylindrical cup of porcelain. The iron hook for attaching the wire depends from its open mouth and is held in place in the cup by a plug of sulphur, which is poured in while melted. The porcelain cup is guarded by an outer shell or casing of iron of similar form. This iron casing, to which the cup is secured by cement, is furnished with a spike or screw, by which it may be attached to the arms of the post. The surface of the cement within and without the porcelain cup is saturated with paraffin. As this substance is repellent of moisture, a continuous film of the latter will never form over the surface of this insulator. It gives very satisfactory results on this account.

Underground Wires.—Greater security against interruption of communication by storms, snow, ice, and malicious interference, but at increased cost of construction, is acquired by placing the wires underground. This practice obtains in most European cities, and largely throughout Germany, where extensive land lines connecting the chief cities and fortresses of the empire have been in operation with entire satisfaction for the past ten years. Such lines, when properly laid, are maintained at a comparatively trifling cost. This reform is now only beginning to be adopted in the United States, and the streets of American cities are still obstructed by overhead wires and disfigured by unsightly posts, which practically have long been banished from European cities.

First Underground Telegraph.—The first trials with underground telegraph lines were made in 1846 by the Prussian lieutenant W. Siemens, but these were far from being successful, because of the imperfection of the insulation employed. The difficulty, however, was afterward completely overcome when attention was directed to the production of insulated submarine cables, and the first successful underground line of any considerable length was laid in 1871 between London and Liverpool.

Submarine Telegraphs.—The first experiments to establish telegraphic communication under water were made in 1839, but were unsuccessful, owing to the defective nature of the insulation. This proved to be the prime difficulty until gutta-percha was used. The first successful subaqueous cable was laid across the Hudson River, between New York and Jersey City, in June, 1848, by the Magnetic Telegraph Company. It was followed in 1849 by one laid in the harbor of Folkestone by Walker, whose line extended from a steamship to the shore, a distance of 3600 feet. The first commercially successful cable of considerable length was that laid in the English Channel in 1851 between Dover and Calais. At the present time submarine cables have been laid in all parts of the world. Of these only the Transatlantic cables will be noticed.

Transatlantic Cables.—The idea of establishing telegraphic communication between Europe and America originated with Cyrus W. Field of New York, who in 1856 succeeded in forming a company to carry the project into execution. The first attempt, in 1857, was a failure, owing to the breaking of the cable 274 miles from the Irish coast while being laid. In a second attempt, in 1858, the cable was actually laid, but it remained operative only long enough to permit of the transmission of a few despatches of congratulation, when it refused to act, owing, as was subsequently ascertained, to defective insulation. After the failure of the third attempt, in 1865, by the breakage of the cable after 1213 miles had been laid, the efforts to establish telegraphic intercourse between the two continents was at length crowned with success in July, 1866. The broken cable of the previous year was also found again, and united with the American continent. Since that time submarine lines have multiplied, and are now in successful operation in all quarters of the world. As yet no cable spanning the Pacific Ocean unites the western shore of America with China or Japan, but the completion of the girdle about the entire globe will probably not long be delayed. There are now nine submarine North-Atlantic cables between Europe and America, of which four belong to the Anglo-American Telegraph Company (laid respectively in 1869, 1873, 1874, and 1880), two to the Western Union Telegraph Company (1881 and 1882), one to the Direct United States Company (1875), one to the Compagnie Française (1879), and the Bennett-Mackey Cable (1884).

Laying of Submarine Cables.—For the purpose of laying the oceanic cables, the latter are formed into suitable lengths and stowed carefully in great tanks prepared to receive them in the holds of steamships built specially for this service, and supplied with self-releasing paying-out appliances so devised that the cable shall not be subjected to injurious strain. Two vessels, for example, proceed to the task in mid-ocean, going in opposite directions and paying out the cable as they proceed, until the terminal connections at the shore ends are safely made.

Construction of the Cables.—Figure 47 (*pl.* 57) exhibits the construction of the deep-sea cable of 1865, that of 1866 being substantially the same. A cable formed of seven plaited strands of fine copper wire constitutes the conductor. This is protected in the following manner: It receives first a coating of an insulating compound (called Chatterton's compound) composed of a mixture of gutta-percha, wood-tar, and resin. Over this comes an accurately concentric primary layer of gutta-percha. Upon this come, alternately, four thin layers of Chatterton's compound and gutta-percha, and over all these a covering of jute. The outer protective covering consists, finally, of iron wires one-tenth of an inch in thickness, enclosed in prepared manilla hemp and wound around the central core in long spirals. The deep-sea portions of this cable had a diameter of 1¼ inches, while the thickness of the shore-sections, where it would be exposed to the action of waves, injury from icebergs, from anchors, etc., was increased to 2½ inches by a heavier protective armor.

It was found, however, that the iron wires of the protecting sheathing soon became corroded. In certain waters, also, the cable is exposed to the attacks of worms, which penetrate between the protecting wires (*pl.* 57, *fig.* 48) and eat into the core. To avoid this danger, C. W. Siemens adopted a plan of constructing submarine cables which Prescott describes as follows: The copper conductor is first covered with a layer of Chatterton's compound and then with two spiral layers of India-rubber. The second layer is so put on that its joints are at an angle of about 90° to those of the first one. The insulated core is then covered with another layer of Chatterton's compound, and again with gutta-percha. The outer envelope of the cable consists of a double layer of tarred hempen bands wound spirally in opposite directions, and lastly of an outer metallic envelope composed of two copper strips wound on spirally, so that the turns lap over one another. The covering of the later Atlantic cables is substantially like that of the 1865 cable, above described; the principal difference consists in dispensing with the tarred-hemp covering of the iron sheathing and in galvanizing the iron wires composing the latter.

Cable Currents.—In the operation of submarine cables, their great length and perfect insulation render it necessary to make provision against the so-called "return currents," which manifest themselves in the sluggishness with which they part with their electrical excitation, and so exert a disturbing influence upon the transmission of signals. Again, the submarine cables with their insulating coverings may be compared, when in an electrified condition, to a condenser or elongated Leyden jar, the gutta-percha covering corresponding to the glass of the jar, the copper conductor within the gutta-percha to the inside coating of the jar, and the iron sheathing to the outer coating. When a current flows in the cable, it induces in the outer sheathing an electrified condition of the kind opposite from that flowing in the line wire, and this by reaction causes induced currents in the latter. This phenomenon is termed "electro-static induction," and seriously interferes with the discharge of the line. To overcome these difficulties, telegraphing through submarine cables is done with comparatively feeble and alternating currents.

To Locate Faults or breaks in a telegraph-line several methods are available. The one most commonly employed involves the use of the so-called "differential galvanometer" and a rheostat, or resistance coil. The principle on which this method is based is that of passing a current of known strength through a series of coils of German-silver wire, the resistance of each of which is known, until the needle of the galvanometer indicates that the resistance obtained is the same as that exhibited by the defective line. The normal resistance of the line is, of course, supposed to be known. The indicated resistance, when found by this mode of measurement, therefore, corresponds to a given length of the line wire, which gives the location of the fault.

The consideration of the subjects of duplex, quadruplex, and multiplex telegraph systems, by which two or many signals may be sent over a line wire simultaneously and in opposite directions, and by which a notable increase in the speed of transmission has been accomplished, would unduly extend this section. For the explanation of these modern improvements the reader is referred to special treatises.

Train Telegraphy by Induction.—One of the most interesting recent advances in telegraphy, that promises shortly to come into general use because of its great utility and convenience, is the maintenance, by several ingenious methods, of communication between moving railway-trains and fixed stations along the line. The practical application of telegraphy to this service is due to several American electricians—notably, to Edison, Gilliland, Phelps, and Smith. The principle involved is that known to electricians as *induction*, in virtue of which an electric current traversing a conductor will cause a current to be generated in a contiguous conductor not in contact with it, and this inductive effect will be appreciable in conductors at some distance from one another. There is no contact or line conductor, the telegraphic communication being obtained simply by the spontaneous reproduction in separate conductors of electrical impulses similar in kind to those originally produced. This system of train telegraphy, which has been introduced on the Lehigh Valley Railroad, in Pennsylvania, has proved a valuable acquisition both in respect of greater safety in the operation of the trains and in the convenience it affords the travelling public.

The General Features of the System are as follows: A short-pole telegraph-line extends along the side of the railroad-track at about the distance of 8 or 10 feet from the track. The poles, which are much smaller than ordinary telegraph-poles, are from 10 to 16 feet high. At the top of each pole is placed an insulator on which is strung a single galvanized-steel (or iron) telegraph-wire. The equipment of the car is extremely simple, mainly consisting in the use of an iron or brass rod or tube, about half an inch in diameter, extending along on each side of the car, under the eaves (or, instead of employing rods or tubes, in many cases the metal roof of the car is used), and connected by an insulated copper wire with the battery and instruments in the car, which are grounded through the wheels and track by a single wire run through the floor, as shown in Figure 2 (*pl.* 59), in which *A* is the roof contact, *B* the rod or strip of metal, *C* the secondary or induction coil, D the double-pointed key with extra contact, E the telephone receiver, F the primary circuit, G the ground contact on axle-box, and H the battery.

The Instruments, which are small and compact, consist of a telephone receiver (attached to the head of the operator), a small secondary coil and "buzzer," and an ordinary telegraphic key. The last two are placed on a board about 10 or 15 inches square, which is carried on the arm of the operator (*pl.* 59, *fig.* 3). The battery is contained in a small box which may be put in any convenient place. Figure 1, which shows the train telegraph-operator sending a message on a moving train, gives an excellent idea of the system in actual practice. The sending apparatus is held in the operator's hands, while the receiver is attached to his ear.

Advantages of the System.—By the adoption of this system all trains on the line of railroad employing it, whether they be in motion or at rest, or whether they be on the main track or on sidings, are susceptible of being placed in instantaneous communication with the division terminal station, and orders may be despatched to any or all of them, regardless of their position. Furthermore, not only the train-despatcher is enabled to communicate his orders to the trains within his division, but also the train-officials are enabled similarly to communicate with the train-despatcher; and they may thus reciprocally inform one another of any accident or other unusual occurrence upon the line.

The system has the incidental advantage of so admirably controlling the movements of trains that it affords a reliable safeguard against collisions. Under the ordinary system, if the station-operator neglects to give an order when the train is at the station, the opportunity is gone, and a serious accident may be the result. With telegraphic communication between fixed stations and moving trains, the neglect may be remedied at any moment. Furthermore, on single-track roads, which are numerous in the United States, the detention occasioned by holding trains to receive telegrams from delayed trains moving in opposite directions may, by the use of train telegraphy, be entirely avoided without incurring the slightest risk, and thereby the capacity of these roads may be largely increased. Moreover, by this system travellers may send and receive telegraphic communications while in transit, which, though of minor value compared with greater safety of train operation, is of importance as an element contributing substantially to the perfection of modern railway-travelling. Until the advent of this system the traveller on a moving train was isolated; now he is in constant communication with the outside world.

Briefly summarized, the advantages claimed for this most ingenious and novel extension of the art of telegraphy are as follows: It will render it possible to move trains safely at shorter intervals and with greater immunity from accident than any system heretofore devised; its first cost and expense of maintenance will be much less than are required for any other thoroughly efficient system; it will have the immeasurable advantage of enabling the train-despatcher to communicate distinct and definite orders to any and all trains, wherever they may be, while the range of any signalling system, no matter how perfect, must necessarily be limited to a few prearranged orders at fixed points.

The art of telegraphy has become a necessary factor in the conduct of public and private business, and plays an important part in the conduct of military operations. To meet the requirements of modern warfare, a special branch of telegraphic service, termed "field telegraphy," has been devised, and developed to a high state of efficiency. Furthermore, the use of the telegraph for the transmission of simultaneous meteorological observations made at various distant points has proved of the utmost value to agriculture and commerce.

Telephones: Reis's Musical Telephone.—Since 1876 there has come into use in all civilized countries an important modification of the electric telegraph by which articulate sounds are transmitted over considerable distances. The apparatus employed is known as the telephone. The first approach to a practical acoustic telegraph was made by Philipp Reis, a German, as early as 1860, who devised the apparatus shown in several modifications on Plate 59 (*figs.* 4, 5), by which musical sounds were transmitted and reproduced at a distance; but it is still a question whether his apparatus ever transmitted and reproduced articulate sounds.

Bell Telephone.—The practical introduction of the art of telephony unquestionably dates from 1876, when Alexander Graham Bell, an American inventor, displayed his articulating telephone (*fig.* 7) at the Centennial Exhibition held in Philadelphia.

Extension and Improvement of the System.—Since its introduction the telephone has become one of the necessities of modern civilization. At first the imperfection of the apparatus and the methods employed limited its use to comparatively short intervals, but at present telephone-lines are working satisfactorily over distances of several hundred miles, and the inhabitants of cities such as Philadelphia, New York, Boston, etc., may by this means converse with one another without difficulty. This of itself suffices to indicate the perfection to which the art of telephony has been brought.

The Telephone.—The details of the system will be found fully elucidated in the volume on Physics, to which the reader is accordingly referred. It may, however, suffice here to indicate in a general way the three essential elements of the method—namely, the telephone, the transmitter, and the exchange-table. Figures 6 and 7 exhibit, respectively, the receiving apparatus and the transmitting apparatus. The telephone (*fig.* 6) consists of a thin metallic diaphragm (E) suitably fixed in a wooden frame (F), and having a bar of magnetized iron secured in the stem of the instrument at right angles to the diaphragm (A), and in such a manner that it may be adjusted. The magnetized bar is never in actual contact with the diaphragm. The bar is, furthermore, surrounded by a coil of insulated wire at the extremity next to the diaphragm (B), and this coil is connected both with the line wire and with the ground (C, D).

Principle of Operation.—When sounds are thrown into the mouthpiece of the instrument, they cause vibrations of the diaphragm, and, as the diaphragm—which is formed of a thin flexible sheet of iron—is made by these vibrations to approach nearer to and recede farther from the magnetized bar, fluctuations in the magnetism of the bar are thereby produced. These fluctuations are reproduced by induction in the coil surrounding the magnet, and by this are transmitted over the line wire to the other terminus, where they cause exactly similar vibrations in the diaphragm of the receiving apparatus, and where, by a reversal of the process above described, there are produced the same sounds that were projected into the apparatus at the transmitting end. The process, then, consists in the conversion of the sound-waves, in the first instance, into electrical waves, the transmission of these over the line wire, and the reconversion of these electrical waves at the other end of the line into sound-waves of the same character as those projected into the transmitting end. Thus articulate speech is conveyed over great distances and intelligibly reproduced with astonishing accuracy. In actual practice the receiving apparatus is a modification of that just described, but the principle of its operation is substantially the same. A detailed description of the various parts of the devices employed would too greatly extend this account.

The Telephone Exchange is a system by which the participators in a local telephone service are brought into communication with one another at will through the intervention of a central office, or exchange, with which the wires of each subscriber are connected. When one wishes to converse with any other, the central office, being signalled for the purpose and told the number wanted, places the caller in telephonic communication with the desired subscriber.

The Long-distance Telephone, by which acoustic communication is maintained between places one hundred, and even two hundred, miles apart, is operated on substantially the same principles, save that in this system it is found necessary to operate with a complete return metallic circuit, or double line.

VI. AËROSTATION.

While the Plates devoted to the subject of locomotion represent vehicles that have been proved upon the touchstone of practical application, Plates 60 and 61 illustrate those inventions which, regarding their mode of action as motive carriages, have thus far achieved only indifferent success.

The ascent of balloons and their movement by and with the winds no more solve the problem of aërostation than the launching and rocking of a rudderless and oarless boat tossed by waves and driven by currents solve the problem of navigation. The desire to move in the air like the bird, to strike out at will in this or that direction, and to keep a predetermined course as the locomotive on the railroad or the vessel on the river or sea, has long been cherished, but still remains unsatisfied. The attempts to realize this desire have been made chiefly in two directions. The first has been to take as a model the flight of birds, bats, and insects, and to construct flying-machines; and the second, to imitate the swimming of fish and to make the balloon guidable.

Aërostats.—The ordinary balloon, which is given a more or less spherical, egg-, or pear-shaped form, rises vertically in a calm, and when there are air-currents ascends in a curved track which, with increasing height, approaches a horizontal line. At a certain elevation it remains suspended or moves in the direction of the prevailing wind. That this phenomenon is caused by the difference of the specific gravity of the filled balloon and the quantity of air displaced by it, and that it is identical with that which is presented by the motion of a piece of wood, or other object specifically lighter than water, ascending from the bottom of the sea, was known before aërostation became a science.

The Invention of the Balloon is claimed for the Portuguese Don Guzman, who in 1736 is said to have made an ascension in a paper balloon filled with "fire-air," though the missionary Vasson is authority for the assertion that a balloon ascended in Pekin in the year 1306. The invention, however, is commonly assigned to the year 1783, when the brothers Stephen and Joseph Montgolfier of Annonay, near Lyons, France, made a practical demonstration of the capability of a light vessel filled with heated air to rise freely in the surrounding atmosphere.

Scheme of Francis Lana.—After the discovery, in 1643, by Torricelli, of the gravity of the air, with which the invention of the balloon was evidently connected, a scheme for aërial navigation was proposed by a Jesuit, Francis Lana, in a work entitled *Prodromo dell' Arte Maestra* (Brescia, 1670). He suggested the employing of four very large copper balls or globes so thin that when exhausted of air they would readily rise. Each globe was to be about 25 feet in diameter and $\frac{1}{225}$ of an inch in thickness; the four balls together would have an ascensional force of about twelve hundred pounds, which would be sufficient to raise the sails with which the machine was to be furnished, together with the gondola and its occupants. As he proposed to exhaust the air by producing a Torricellian vacuum, he was evidently ignorant of the invention, in 1648, of the air-pump by Otto von Guericke. In 1678, Sturm of Altdorf, near Nuremberg, also pursued this idea, and after Cavendish's discovery of hydrogen gas, in 1766, Professor Black of Edinburgh clearly expressed the theory that, on account of the small specific gravity of this gas, a light envelope filled with it would ascend in air. This theory was confirmed in 1782 by the experiments tried by Kratzenstein, Lichtenberg, and Cavallo with soap-bubbles filled with hydrogen gas.

Lana's and Sturm's ideas were, of course, practically of no value, since the pressure of the exterior air would immediately have caused the copper balloon to collapse. To resist the external pressure, a reservoir which is to be made lighter by pumping out the air will require such thick walls that its weight will far exceed the admissible limit. But since the discovery of hydrogen gas—which, while exerting a pressure equal to that of the atmosphere, weighs only one-fourteenth as much—it is remarkable that the idea of using a containing vessel made of some light substance like paper, instead of the soap-bubble employed for the purpose, did not suggest itself.

First Hot-air Balloon: Montgolfière.—The Montgolfiers, who were paper-manufacturers, and who were distinguished through their contrivance of the hydraulic ram, probably did not fully comprehend the principle of their invention; certainly they did not develop it so far as to use specifically light gases, etc.; but, as is well known, they received the happy inspiration for their invention by observing the ascending and moving clouds. "If such a cloud could be enclosed in a light envelope, this envelope would be carried through the air." This conclusion was the result of correct observation. "And as smoke"—thus, no doubt, further reasoned the inventors—"ascends like a cloud and moves onward, all that is required to raise a light balloon of paper or linen is to cause the smoke to pass into it from a fire kindled beneath." Paper, however, being too liable to tear, and the meshes of linen being too open, the Montgolfiers constructed a linen balloon lined with paper. On June 5, 1783, a globe of this description (*pl.* 60, *fig.* 1), 117 feet in circumference, inflated with hot air and gases of combustion, ascended at Annonay to the astonishing height of 1600 feet, and in ten minutes descended one and a half miles from its starting-point. This was the first successful experiment with the balloon, and the news of the event spread rapidly through all the countries of Europe. The balloon invented by the Montgolfiers was called a "fire-balloon," or, as styled by the French, a *montgolfière.*

It is worthy of notice, in respect of the position of empiricism and science toward invention, that the Montgolfiers believed that the ascent of the balloon was caused by the smoke and gases of combustion with which it was inflated, and that they did not recognize that the balloon owed its lifting-force to the air expanded and made lighter by the heat of the smoke.

Experiments with Hydrogen Gas.—Science had now taken hold of the problem—or, rather, was led by the Montgolfiers in the right direction, long sought, but never before found. With the correct interpretation of the phenomenon of the rise of the hot-air balloon, the use of hydrogen suggested itself; but there were doubts, from a scientific standpoint, of the possibility of preparing a sufficiently light and dense envelope to retain it. There were also fears of the inflammability of the hydrogen evolved in large quantities. The venture seems small enough at the present time, when we see hundreds of toy-balloons filled with hydrogen, or with ordinary illuminating gas, carried about and occasionally flying in the air. We know, however, that the permeability of the india-rubber of which they are made soon renders them useless, and therefore can form a conclusion as to the difficulty at that time of preparing a gas-tight balloon of large dimensions—a task which even at present it is by no means easy to accomplish.

Two brothers of the name of Robert, directed by M. Charles, professor of physics at the Conservatoire in Paris, endeavored by the use of taffeta covered with a thick coat of resinous varnish to fabricate a more dense, but nevertheless sufficiently light, envelope, and to give the balloon a firmer construction by covering it with a network of cords to which a gondola might be suspended. In the course of the first years of their experiments they filled with hydrogen gas and liberated a number of balloons, whose aërial flights were followed by the public with intense interest. This interest arose as much from the fantastic dreams and sanguine hopes which were associated with the near future of aërostation as from the more earnest reflections and quieter expectations which were induced by the prospect of a profitable application of the balloon to scientific purposes and to strategical and other practical uses.

First Hydrogen-gas Balloon: Charlière.—The first "air-balloon" was sent up from the Champ de Mars, in Paris, August 27, 1783. This balloon, 13 feet in diameter, manufactured by the brothers Robert according to directions of M. Charles and inflated with hydrogen gas, rose rapidly about 3000 feet. At the expiration of three-quarters of an hour it fell in a field about fifteen miles from the place of its ascension, where it was discovered by some peasants, who, fearing it was some uncanny thing that might do them harm, immediately tore it in shreds. A balloon of this description was then called an "air-balloon," because at that time hydrogen gas was known by the name of "inflammable air;" by the French the hydrogen balloon was styled a *charlière.*

First Aëronauts.—The first year after their invention the Montgolfiers were frequently engaged in sending up balloons filled with smoke or hot air. These ascensions, which were accompanied by festivities and the thunder of cannon, were watched with enthusiastic interest not only by Frenchmen, but also by the entire world. On the 19th of September, 1783, the Annonay experiment was repeated by Joseph Montgolfier at Versailles in the presence of the king, the queen, the court, and an immense concourse of spectators. Below the balloon there was suspended a basket or cage in which had been placed a duck, a cock, and a sheep. The balloon rose to the height of about 1500 feet, and, with the animals—which were thus the first aëronauts—descended in safety two miles from the starting-point.

Pilâtre de Rozier, a young naturalist, was the first human being who ascended in a balloon. On October 15, 1783, and on several succeeding days, he mounted the gondola attached to a *montgolfière* and made several experimental ascents at moderate heights, the balloon being held by ropes. He now resolved to undertake an aërial voyage in an unconfined balloon. Notwithstanding the opposition of Louis XVI., who at first would only consent that two condemned prisoners might be allowed to venture, De Rozier succeeded in overcoming the king's objections and obtained permission to undertake the voyage. On November 21 of the same year, in company with the marquis D'Arlandes, he ascended from Paris in a free *montgolfière* (*pl.* 60, *fig.* 2), and after rising to a height of 3000 feet descended in safety five miles from the starting-point.

On December 1, 1783, MM. Charles and Robert ascended from Paris in a free hydrogen balloon to the height of about 2000 feet, and, after remaining for some time at that elevation, descended at Nesle, about twenty-six miles from Paris, where M. Robert left the gondola, and M. Charles ascended alone to the height of about two miles, and in half an hour descended three miles from the starting-point.

Early Experiments in America.—That the interest in the subject was not confined to European countries is evidenced by the fact that about this time experiments in the same direction were made in Philadelphia. Two members of the American Philosophical Society, David Rittenhouse and Francis Hopkinson, made some experiments by connecting a number of small balloons inflated with hydrogen gas. After successfully sending up this combination, which was attached to a rope, a carpenter named James Wilcox was induced to make an ascension with them. He rose to the height of several hundred feet, but, becoming alarmed, he made, according to instructions, an incision in several of the balloons, whereupon he descended without serious injury.

Blanchard's Balloon.—M. Jean Pierre Blanchard, who prior to the experiments of the Montgolfiers had made unsuccessful attempts to construct flying-machines, and who subsequently became distinguished as an aëronaut, endeavored, immediately after the invention of the balloon, to make it available for long voyages. Not meeting with sufficient encouragement and assistance in France, he went to England, and, accompanied by an American, Dr. John Jeffries of Boston, on January 7, 1785, made the voyage to Calais from the chalk cliffs of Dover. It cannot be stated with certainty that the balloon used by Blanchard for this voyage had the same form of construction as that shown in Figure 3, in which he made an ascension from Paris, March 2, 1784. It will be seen that it is provided with a parachute as well as with a rudder, which Blanchard considered very important. The net carrying the gondola had, however, been already used by Professor Charles for his first balloon.

De Rozier's Double Balloon.—On June 15, 1785, Pilâtre de Rozier—who, as has been previously stated (p. 366), was the first to rise in a balloon—made his last, and to him fatal, ascension. It was his intention to cross from Boulogne to England, in imitation of the voyage of Blanchard and Jeffries, though in an opposite direction. For this purpose he constructed a double balloon by suspending a *montgolfière* 10 feet in diameter beneath a *charlière* 37 feet in diameter, so that by controlling the fire beneath the former he could increase or diminish the ascensional power at pleasure without waste of gas. Rozier was accompanied by a young man named Romaine Lainé, and for thirty minutes after their ascent everything betokened a successful voyage, when suddenly the entire apparatus was observed to be in flames, caused by the ignition of the gas, which either descended to the fire from the upper balloon or was reached by the fire rising from the lower.[1] By this accident both adventurers lost their lives, being precipitated upon the rocks near Boulogne from a height of about 3000 feet.

First Application to Military Purposes.—This disaster, being obviously the result of carelessness, did not deter others, and there followed in rapid succession numerous ascensions, generally of the character of exhibitions by athletes and circus performers, though actual aërial voyages to predetermined distant points were occasionally attempted. The higher useful application, however, still remained in the projective stage until 1794, when the balloon was first used for military purposes during the war of the French republic against Belgium. In the battle of Fleurus two companies —the so-called *aërostiers*, especially organized for this purpose—reconnoitred, although without important results, in the manner shown in Figure 6 (*pl.* 61). In the civil war in America (1861–1865) a regularly organized balloon corps was employed, which operated with some success in reconnoitring.

First Application to Scientific Purposes.—The first application of the balloon to more earnest scientific purposes was made in Germany in 1803. On the 18th of July, Robertson and Lhoëst ascended in Hamburg, and after remaining five and one-half hours in the higher regions descended near Hanover, enriched by many observations in regard to frictional electricity, galvanism, sound, boiling-point, heat of the sun, and optical and physiological phenomena. For this ascension the balloon (*fig.* 6) which was used in the battle of Fleurus, and which Robertson had purchased, was employed.

Importance of the Montgolfiers' Discoveries.—Reference has been made to the fact that to the brothers Montgolfier belongs the merit of being the inventors of the envelope which, when filled with hot smoke, heated air, or specifically light gas, forms the balloon, or aërostat. This merit should

[1] In most works on aërostation this is said to have been the cause of the disaster. G. May, in his work on *Ballooning* (London, 1885), says: The marquis De Maisonfort wished to accompany them. He cast into the hat of Pilâtre a rouleau of two hundred louis and placed his foot in the boat; but the aëronaut gently pressed him back, saying, "I cannot take you with us, for we are not sure of the wind nor of the air-craft, and we desire to risk only our own lives." Maisonfort—fortunately for himself—remained a simple spectator of the departure, and it is to him we owe the exact account of the drama enacted under his eye, which is as follows:

A few minutes after their departure the voyagers were assailed with a contrary wind, which threw them toward land. It is probable that, in order to descend and seek a more favorable current of air which might lead them on to the Channel, De Rozier pulled the valve of the balloon, but the cord attached to this valve was very long—it was not less than 100 feet, as it passed from the boat placed below the *montgolfière* up to the top of the balloon—and it consequently acted with difficulty. The very severe friction which it occasioned tore the valve. The material of the balloon was weakened by the great number of preliminary trials which had been made at Boulogne, and several attempts at departure. It was torn near the valve, and the rent extended over many feet; the valve fell inside, and the balloon was emptied in a few moments. There was, therefore, no inflammation of the gas (as has been repeatedly stated) when suspended in the atmosphere. It was noticed after the fall that the stove under the *montgolfière* had not been lighted. The real cause of the tragedy was in the balloon being emptied of its hydrogen, falling over the *montgolfière*, and the weight of the whole mass being dragged with terrible velocity to the earth. —ED.

not be underestimated, for the invention would not have been accomplished had not the idea been recognized that such a balloon must have a considerable diameter, and had not practical difficulties in the way of preparing a sufficiently tight and firm envelope of such enormous dimensions been successfully overcome. In fact, the first *montgolfière* had a diameter of over 39 feet and weighed about five hundred pounds. The idea of utilizing the flight of the clouds or the ascension of the smoke must certainly be called ingenious.

Charles's Improvements in Balloon Construction.—However, with the improvement above named, *montgolfières* came in course of time to be entirely abandoned, and subsequently have been used only for amusement, while the *charlières* formed the basis of the more perfect constructions for aërial voyages and more earnest purposes. Charles, in connection with Robert, had also provided the balloon with the accessories absolutely required for safer ascensions and voyages. He devised, as above noticed, the net to carry the gondola; and to diminish at will the internal pressure of the gas, which was liable to cause explosions, as well as to discharge the gas for the purpose of descending, he arranged in the vertex of the balloon a suitable valve which as required could be opened and closed by the voyager by means of a rope carried through the balloon. He used as the material of his balloon taffeta made impermeable by the application of a solution of rubber; he provided ballast, an anchor, and an instrument for measuring the altitude.

The Use of Ballast was suggested by practical experience gained in Charles's first voyage (p. 367), when he found that the balloon, suddenly relieved of the weight of one hundred and forty-three pounds as his companion Robert left the car, ascended again with lightning rapidity to a height of about two miles.

Hydrogen—for the use and preparation of which in great volumes Charles was especially distinguished—however, was gradually displaced by the cheaper, though not quite so suitable, illuminating gas, and the use of this material became more general as city gas-works increased in number. The seven to eight times greater specific gravity of illuminating gas as compared with hydrogen was counteracted by constructing larger balloons. Illuminating gas was first used for this purpose by the Englishmen Coxwell, Charles Green, and his son George, who made a great number of ascensions and aërial voyages.

Green's Great "Nassau Balloon."—Figure 7 (*pl.* 60) represents the balloon used November 7, 1836, by Charles Green for his voyage from London to Weilburg, in the duchy of Nassau, in which he made the distance of about five hundred miles in nineteen hours. Green was accompanied in this journey by Robert Hollond and Monck Mason, the latter of whom published a very full and interesting account of the trip. The balloon contained about 85,000 feet of gas; it was subsequently named the "Nassau Balloon," and acquired great notoriety through its frequent ascensions.

The very large balloons constructed by Green and Coxwell (one by the latter, which ascended in 1851 at Leipsic, had a height of 66 feet and a volume of 35,000 feet) were, however, far surpassed by that sent up in Paris by Nadar in October, 1863.

Nadar's Balloon, "*Le Géant*," contained more than 211,000 feet of gas and carried a two-story wicker-work gondola, with physical instruments, photographic apparatus, food, beds, toilet-tables, etc. The unfortunate accident (*pl.* 60, *fig.* 11) which occurred near Nienburg, in Hanover, at the descent of this balloon, which carried nine persons, excited universal interest. The voyagers—among whom, besides Nadar and his wife, was the well-known aëronaut Godard, who acted as steersman or captain—could not provide for a sufficient escape of the gas. Hence the balloon, descending only sufficiently to allow the heavy gondola to drag on the ground, was carried by a strong wind over hedges and ditches, damaging buildings, destroying railroad embankments, and breaking telegraph-wires, until finally it remained suspended in a forest near Rethem. The "Géant" made three more ascensions in 1867. Figure 4 represents a still more disastrous catastrophe than that which happened to the "Géant"—namely, the bursting of the "Neptune," which, with the valve closed, was caught by a storm while held by a cable.

Balloon Inflation.—Figure 8 shows the process of getting a balloon ready for a voyage. The balloon is seen already filled, but held down by its net, with the aid of sand-bags. Near by are seen the large gasometers from which the supply of gas has been taken. The cables thereupon are freed from the sand-bags and connected with the car, meanwhile being held fast by three or four ropes in the hands of attendants, who, on receiving the signal from the aëronaut, let go simultaneously, and the balloon starts off on its aërial voyage.

Captive Balloons.—To be sure of the course the balloon would take, it was customary, before making a voyage, to send up small balloons, and to wait until they took the desired direction. Aëronauts, however, frequently risked the experiment of finding an altitude where the direction of the wind would afford the required horizontal motive-force, the opinion being held that, according to observations (which, generally speaking, have proved correct), air-strata at different altitudes move in the most varying directions. These experiments have not, however, been uniformly successful. Even in making a simple ascension the place of landing could never be determined previously with any certainty; still less could the balloon be kept suspended at a certain point, which would have been very desirable for making scientific observations. Finally, to effect the descent, the costly gas had to be discharged and wasted when its retention might have been of great advantage. The attempt has recently been made to obtain all these favorable conditions by holding the balloon captive.

Strictly speaking, the balloon used for military purposes (*pl.* 61, *fig.* 6) is a captive balloon; but the purpose in view is to consider balloons which are held captive and are let up and drawn down by machine-power. Besides its own weight, such a balloon must carry the occupant of the car and the weight of a long cable reaching to the earth. Hence, under otherwise equal conditions, its carrying-power must be considerably greater than that of a free balloon, and it must, therefore, either be made more voluminous or be filled with a lighter gas—that is, with hydrogen instead of illuminating gas.

Giffard's Balloon.—By combining both these expedients, the captive balloon constructed in 1869 in London (*pl.* 61, *fig.* 5) was made a giant carrying an omnibus-like gondola. Its diameter was 120 feet and its volume not less than 425,000 cubic feet. It was twice as large as "Le Géant," previously mentioned, and two and two-fifths times as large as the one at the Paris Exhibition of 1867. The filling of such a large balloon with illuminating gas being very costly, and with hydrogen gas still more so, its constructor, Giffard, was very successful in his endeavors to prepare as light an envelope as possible, using two layers of linen and one of muslin, with layers of caoutchouc between them, and over all seven layers of caoutchouc and oil varnish. By this the weight of the envelope alone was increased 6160 pounds, but the fabric was so impermeable that for weeks no additional gas had to be supplied. The balloon was placed in a canvas-covered frame building, and was secured to a cable about 2100 feet long, which was carried over a guide-pulley, placed underground, to the drum of a steam-windlass. In ascending, the balloon unwound the cable, and was drawn down by it without the necessity of discharging any gas. Financially the enterprise was not a success, especially as, after having been in use but a few weeks, a heavy storm and the carelessness of the engineer caused the breaking of the cable and the escape of the "captive," which had to be captured and refilled. Similar enterprises have been attempted, and with considerable *éclat*, at several more recent exhibitions.

The relation of a captive balloon to the currents of the wind differs entirely from that of a free balloon. While the latter yields to the shocks and pressures of the storm and the aëronaut scarcely feels them, every shock of the wind is disagreeably felt in the captive balloon; and if it be not quickly hauled down by the cable, it is liable to get into the critical situation already described, and illustrated in Figure 4 (*pl.* 60).

Dirigible Balloons.—Shortly after the invention of the balloon it was confidently believed that means for its successful guidance could readily be devised, and consequently sails and rudders (with which Blanchard's balloon, *fig.* 3, was provided) were at first employed. But these naturally proved useless, since, instead of combating the wind, they presented to it additional points of attack. A vessel on river or sea is able to advance against the wind by means of the sails, since tacking can be effected by the rudder operating against the resistance of the water.

Similarly, steering, after a fashion, may be accomplished in aërostation with the help of a resistance supplementing that of the air. A project of this kind by an anonymous aëronaut is represented in Figure 7 (*pl.* 61). The balloon, provided with sails and secured to a rudder floating in the sea, is sufficiently distended to tighten the towing-ropes in a calm without raising the rudder to any extent. With a rising wind, it is moved forward with the assistance of the sails. By placing the rudder, by means of the towing-lines, parallel to the direction of the wind, the balloon, with but a small resistance to overcome, will be moved exactly in the direction of the wind. By placing the rudder horizontally at right angles to the course of the wind, the balloon is also moved in the direction of the wind, but more slowly, because of the greater resistance afforded by the rudder. By placing it, however, obliquely to the direction of the wind, the balloon must take a course deviating more or less from the direction of the latter; and hence to a certain extent the direction and the rapidity of its motion are under control. On account of the artificial resistance the balloon receives, however, a wind-pressure of considerable energy might readily bring about a catastrophe like that mentioned in describing the captive balloon (*pl.* 60, *fig.* 4). Moreover, by giving a special form to the balloon, a species of steering—that is, the bringing about of a movement in another direction than that of the wind —may also, without aid from any external resistance, be effected by the resistance of the air itself. The term "fish-shape" or "cigar-shape" is applied to such forms as are illustrated in Figure 9.

By uniting with this construction a trapeze formed by ropes hanging vertically from the ends of the balloon and connected parallel to the longitudinal axis by a bar, and by further suspending to this bar a heavy gondola, or car, in such a manner that it may be shifted backward and forward upon it, then, in ascending in a calm, a different direction from the vertical may be taken in consequence of the gondola being shifted into an oblique position in reference to the axis of the balloon, the resultant of the two components—the upward impelling force and the resistance of the air—in this case being in a direction other than the vertical. By combining this motion with an alternate ascent and descent, a horizontal advance in a calm and against the wind becomes possible; it will take place in a zigzag track laid in a vertical plane.

The alternate aseent and descent are effected, respectively, by throwing out ballast and letting out gas, and also by the use of the air-reservoir. This air-reservoir is a second balloon, placed in the interior of the main balloon and charged with air, which, being specifically heavier than that at higher altitudes, enables the aëronaut by its partial discharge to render the aërostat relatively lighter, thus imparting considerable ascending-power. This contrivance was proposed and experimented with by Meunier shortly after the invention of the balloon.

Joulie's System.—The plan proposed by Joulie is, however, more effective. A reservoir of gas attached to the gondola and communicating with the balloon, by a pump and flexible tube is made to receive a quantity of the gas in a compressed state by the action of the pump, or to deliver it to the balloon, as may be determined, the ascending-power of which is decreased in the former case and considerably increased in the latter; the alternate compression and dilatation of the gas thus effect respectively the descent or ascent of the balloon without the discharge of gas or ballast.

Propellers.—The rudder is effective only in case there is a propelling apparatus operated by some form of motor. An apparatus of this kind will work the more advantageously the less resisting surface it offers to the wind counteracting the motion. Its most suitable form of construction thus far has been that of the propeller, or ship-screw, which, to be at all effective, on account of the comparatively small surface, requires to be given a great velocity of rotation. Fully recognizing this, modern inventors have adopted for dirigible aërial vessels screws similar to those in Figures 1 to 3 (*pl.* 61), arranged between the balloon and car. The cigar- or fish-shape has also been preferred for these dirigible balloons, for the reason that though, under otherwise equal circumstances, the ascending-power depends not on the form, but on the volume, the resistance of the air to be overcome is the smaller the less the cross-section of the balloon that is presented to it in the direction of the motion. The form that presents the least cross-section—that is, the fish- or cigar-form—is therefore the best for the purpose in view.

It is worthy of notice at this point that the earliest correct suggestions for controlling the movement of balloons emanated from the Francis Hopkinson above named. He wrote a letter to his friend Dr. Benjamin Franklin, dated Philadelphia, May 24, 1784, in which he recommended that the balloon should be made oblong instead of spherical, and that it should be provided with a large and light wheel at the stern. The letter continues: "This wheel should consist of many vanes, or fans, of canvas, whose planes should be considerably inclined with respect to the plane of its motion, exactly like the wheel of a smoke-jack. If the navigator turns this wheel swiftly round by means of a winch, there is no doubt but it would (in a calm, at least) give the machine a progressive motion, upon the same principle that a boat is *sculled* through the water." Nearly seventy years elapsed before these suggestions were reduced to practice.

Giffard's Dirigible Balloon.—Giffard had already experimented in 1852 with a construction of this kind (*fig.* 1). Giffard's aërial vessel was pointed at both ends, and was filled with illuminating gas. Beneath it, and suspended therefrom by cords, was a longitudinal shaft carrying at one end a triangular sail. This could be turned about a vertical axis, and was designed to serve the purpose of a rudder. At a distance of about 20 feet below this shaft was suspended a platform of wood, on which was placed a small steam-engine which actuated a screw-propeller. The weight of the balloon and its machinery was nearly fourteen hundred pounds. With this machine Giffard made several voyages, and was able to make perceptible headway against a strong wind, and to guide the vessel in any desired direction. The danger from sparks from the furnace, however, made these experiments, as may be imagined, extremely hazardous.

Porter's Dirigible Balloon.—Rufus Porter of Washington next appeared with a satisfactorily-working model, and later on with a gigantic air-vessel (*pl.* 60, *fig.* 9). Its balloon had a length of nearly 163 feet and a greatest diameter of about 16½ feet. Its car formed a saloon 59 feet long by 8¼ feet wide and high, and the motive-power was supplied by a double-cylinder steam-engine of four-horse power. On the trial-trip of the apparatus it was, however, found that the linen used in the envelope had been so rotted by the varnish with which it was coated that it allowed the hydrogen gas to escape; and a satisfactory trial of the device does not appear to have been made.

Later on, Mariott, in California, constructed a similar air-vessel, with which, it was claimed, satisfactory experiments were made, July 2, 1869, by the "Aërial Steam-Navigation Company;" but nothing seems to have been done thus far in regard to the proposed building of a larger vessel.

De Lôme's Dirigible Balloon.—In consequence of the interest in aëronautic experiments awakened by the siege of Paris, Dupuy de Lôme designed the apparatus seen in Figure 2 (*pl.* 61). A large vessel with a balloon having a capacity of about 123,500 cubic feet was constructed according to this design, and on February 2, 1872, made a successful trial-trip to Fort Vincennes. The balloon was filled with hydrogen, and the car carried fourteen persons, of whom seven at a time were employed in working at a capstan which controlled the shaft of a propeller having two wings each 10 feet in length. With this apparatus a speed of six miles per hour was attained, and a deflection of twelve degrees from the direction of the wind. The motive-power was less efficient than that employed by Giffard.

Haenlein's Dirigible Balloon.—A satisfactory trial-trip is also said to have been made in 1873 in Brünn with a similar construction patented in 1865 by Haenlein. This vessel was provided with a supplementary air-reservoir, or air-pocket, the principal object of which was, however, to keep the balloon tense even when gas was withdrawn from it. Gas was, however, uninterruptedly withdrawn by the gas-engine which supplied the motive-power. This motor was of somewhat peculiar type, having four cylinders, and possessing other special features designed to secure lightness. The decrease in ascending-power caused by the withdrawal of gas for driving the engine was to be compensated for chiefly by the evaporation of the water used for cooling the cylinders of the machine, and further by throwing out ballast.

Motors.—All the experiments made in this direction have demonstrated that rudders used with the application of motive-power allow sufficient steering of an aërial vessel in a calm, so that motion in any desired direction may be effected; and it is claimed, also, that satisfactory progress has been made in a calm air and with a moderate wind. But considerable currents of air cannot be overcome, and, besides, the carrying-power is greatly reduced by the weight of the motor. The solution of the problem of constructing a motor which with the required power shall be considerably lighter than those existing at the present time would bring the question of the practicability of guiding aërial vessels nearer its solution. Aluminium, on account of its lightness, may furnish the material desired, but on account of its high cost it cannot yet be made available.

Gas-motor.—Haenlein considers the gas-motor as best adapted for the purpose, and the use of hollow parts in the construction of the engine as the most effective method for reducing weight to the lowest degree, this being not only in imitation of the hollow-boned skeleton of the bird, but also in accordance with a true *dictum* of the doctrine of strength. Besides, the hourly consumption of gas amounts only to 25 cubic feet per horse-power; so that a volume of, say, 150,000 cubic feet would not be notably decreased in an ordinary run.

Tissandier's Electric-motor Balloon.—Tissandier, a French savant, and a pupil of Giffard, was the first to conceive the idea of employing electricity as the motive-power for a navigable balloon in place of steam- and hand-power. The source of electrical energy which he used was the storage-battery. His first trial was with a small experimental balloon of elongated form, which, when inflated with hydrogen, preserved an ascensional force of 2 kilogrammes (4.4 pounds). With the storage-battery cell was connected a miniature motor of the Siemens type (weighing about one-fourth of a kilogramme, or less than a half-pound), which was made to drive a propeller consisting of a pair of vanes each 10 centimetres (about 4 inches) long, the battery, motor, and propeller being supported on a platform suspended from the netting. This navigable balloon was capable of attaining a speed of about 3 metres (nearly 10 feet) per second. It was exhibited at the Electrical Exhibition in Paris in 1881, where it attracted the favorable notice of the judges.

Encouraged by the success of this model, Tissandier undertook the construction of a large aërostat on the same plan, and eventually succeeded in building one 92 feet long and 30 feet in its greatest diameter, with a capacity of 38,000 cubic feet. This, when inflated with hydrogen, had an ascensive force of 2800 pounds. The aërostat (*pl.* 61, *fig.* 4) was provided with a two-bladed propeller 9 feet in diameter, while a triangular sail, placed at one end of the balloon and close beneath it, was designed to be operated as a rudder. With this apparatus Tissandier made an ascension on October 8, 1883. At the height of 1600 feet the wind was blowing at the rate of six miles per hour, and he was enabled, by turning the head of his balloon against the wind, to keep it motionless for some minutes, its propeller making three revolutions per second. The rudder, however, proved insufficient. By turning the aërostat with head pointed with the wind, a marked acceleration of speed was attained, and a considerable deviation from the direction of the wind could be obtained with the aid of the rudder. The use of electricity as the motive-power of a dirigible balloon was by this experiment demonstrated to be decidedly superior to that of hand- or steam-power.

Renard and Krebs's Electric-motor Balloon.—Encouraged by the success of Tissandier, two officers of the French army, MM. Renard and Krebs, assisted by a government appropriation of one hundred thousand francs, constructed a navigable aërostat embodying the same general features of construction, though modified in a number of points and employing electricity as the motive-power. The success achieved by these experimenters in directing the motion of their aërostat at will was so decided, and so greatly in advance of anything previously achieved, that their results mark an era in the history of the science of aërostation.

Professor W. le Conte Stevens, in an instructive paper entitled "Recent Progress in Aërial Navigation," which appeared (July, 1885) in the *Popular Science Monthly*, gives the following account of these remarkable results: "The pecuniary resources at their command gave them a great advantage over Tissandier in the ability to construct a balloon much larger than that with which Tissandier's success had been achieved, and this permitted the application of a motor nearly seven times as powerful as the one previously employed. Their balloon (*pl.* 61, *fig.* 3) is 166 feet long, 28 feet in greatest diameter, its capacity 67,000 cubic feet and ascensional power nearly 5000 pounds. . . . . The details of the battery and motor have not been given to the public by Captain Renard. The rudder is almost a parallelogram in form and thickest in the middle, the cloth being tightly stretched over a light framework, so as to present a rigid surface to the air. The propeller is fixed to the extremity of a long shaft and placed at the front instead of rear of the balloon. The front end of the machine is thicker than the rear end. . . . . The balloon is filled with hydrogen, but within it is a subsidiary balloon connected by a tube with the cage, where air can be pumped in or out at pleasure, thus varying slightly the specific gravity of the mass as a whole, and enabling the aëronauts to vary their elevation at will.

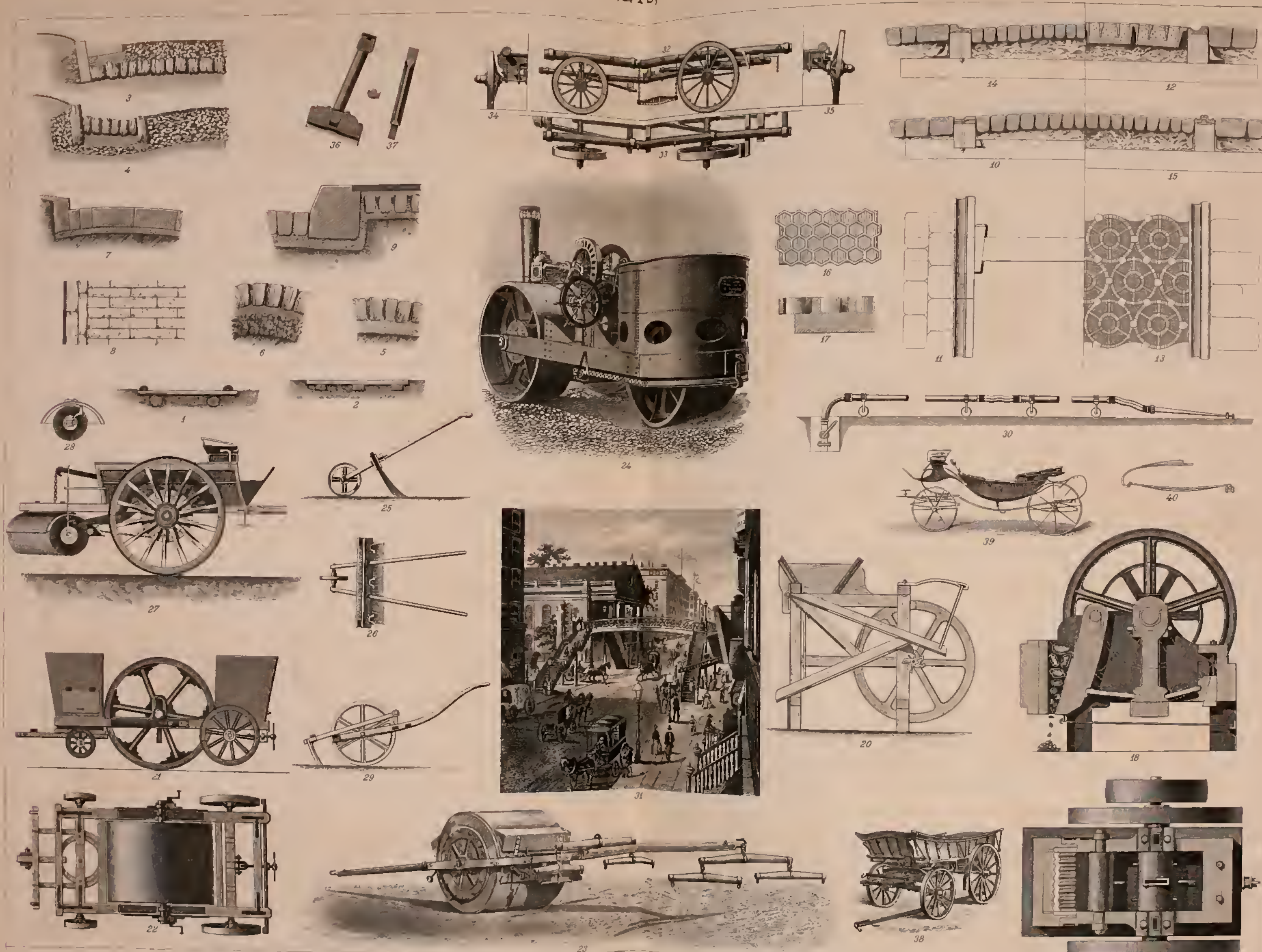
"On August 9, 1884, an ascent was accomplished with this balloon, the atmosphere being almost perfectly calm. A journey of nearly two miles was made in a southerly direction, then over a mile westward, after which the balloon was turned northward and eastward. Very slight motion of the rudder was needed to execute these curves. Twenty-three minutes after their flight was begun the aëronauts were immediately over their starting-point, having made a trip of not quite five miles. In descending it was necessary to move backward and forward several times in succession, alternately reversing the direction of the propeller. The return to the ground was at the very spot from which the departure had been made. This remarkable feat was thus accomplished almost exactly one hundred and one years after the ascent of the first hydrogen balloon, sent up by Charles from a point but a few miles distant (p. 366). . . . . On the 8th of November two successive journeys were taken, the balloon returning each time to its point of departure, and attaining a speed of nearly fifteen miles an hour independently of the wind, which was blowing at the rate of five miles an hour."

From this interesting account it would appear that to France, which was the birthplace of the balloon, the world is indebted for its highest development. Nevertheless, though we may reasonably expect continual improvement in its manageability along the lines followed by Tissandier and Renard and Krebs, it is scarcely within the bounds of possibility that it should ever attain to any commercial importance as a means of locomotion. By modifications of construction which shall still further decrease its resistance, and by increasing the efficiency of the motor—that is, by increasing its power in relation to its weight—it is possible that a balloon may be built with which a speed of twenty-five or thirty miles in a calm may be attained; but the restriction of its use to fair weather and a still atmosphere, its enormous volume, and its very limited carrying capacity must always render the thought of competition with the railway or the steamship too visionary to be entertained seriously. For one useful purpose, however, the balloon has already fully demonstrated its value, and in the future will, in all probability, be found indispensable—that is, in warfare. The ability to direct the motions of a balloon at an elevation sufficiently great to insure its safety from an enemy on the ground must render it a most valuable adjunct as a means of obtaining information of the strength, disposition, and movements by an army, and of conveying aid and information to and from the forces within a beleaguered city or fortress shut off from other means of communication with the outside world.

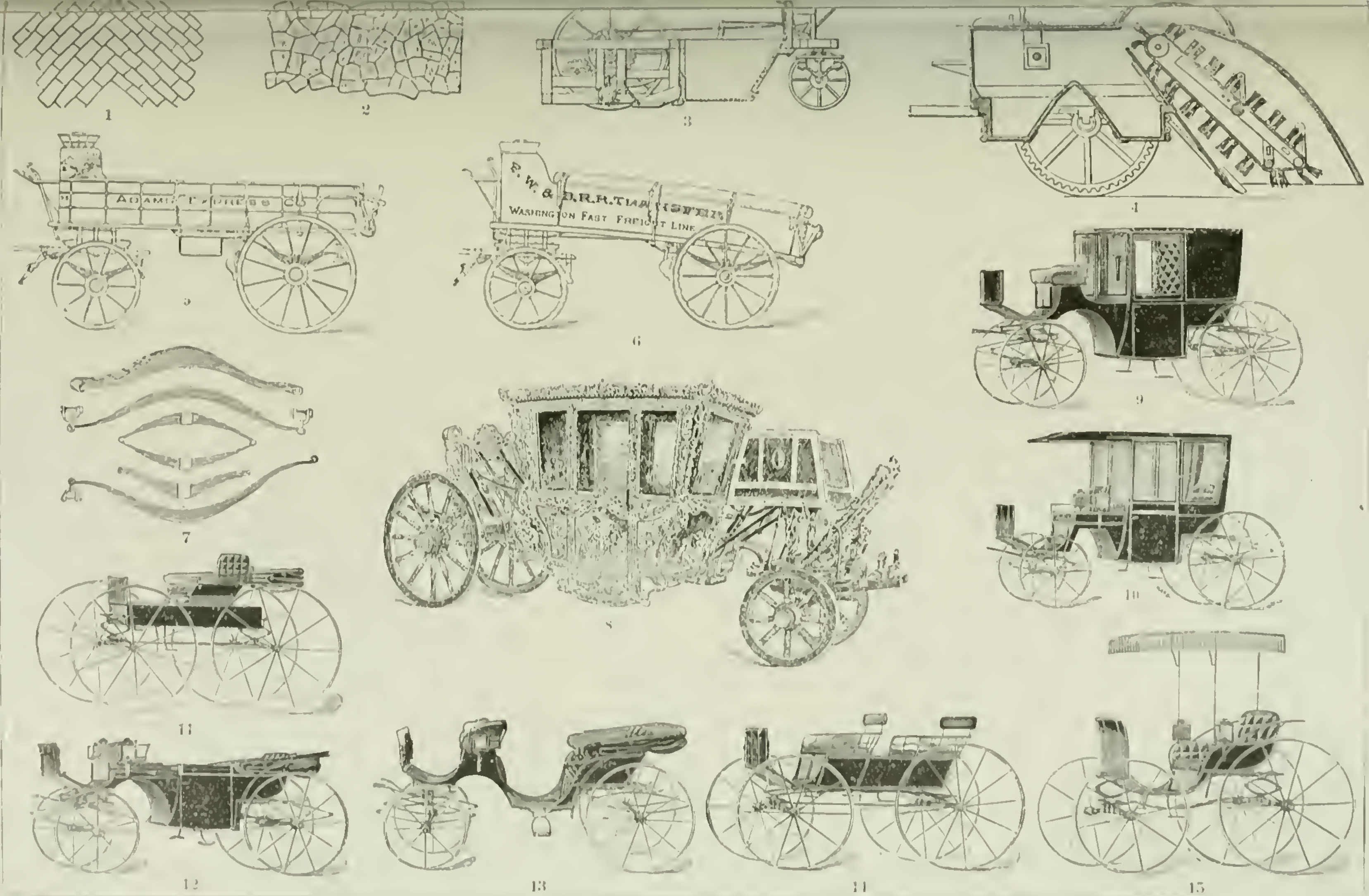
Notable Balloon-ascensions.—The most remarkable ascensions on record, so far as relates to the altitude attained by the balloon, were those made, respectively, by the French savant Gay-Lussac, September 16, 1804, when he reached a height of over 23,000 feet, and of the English meteorologist James Glaisher, on September 5, 1862, when, in company with Mr. Coxwell—an experienced aëronaut—he made a voyage from Wolverhampton, England, and ascended to an immense height. The exact altitude reached will never be known. The last observation of the adventurous voyager showed a height of 29,000 feet, and the balloon at that moment was rising at the rate of 1000 feet per minute; and at the next moment Mr. Glaisher became insensible, and so remained for several minutes. There is good reason to believe that on this remarkable voyage the balloon reached the altogether unprecedented height of 37,000 feet (seven miles). It is of interest to notice in connection with the foregoing remarkable experiences that both were undertaken in the interests of science, and that a number of important data were ascertained. America also has contributed some noteworthy ascensions, and the late Mr. John Wise, a noted aëronaut who made an immense number of ascensions, deserves special mention for the substantial aid which his observations have rendered to meteorological science.

Flying-machines.—Stimulated by the inspiring spectacle of the flight of birds, it is not to be wondered at that the problem of constructing a flying-machine—that is, a machine that should be self-raising and self-propelling—should have taken a strong hold upon the imaginations of ingenious men. Indeed, the efforts to solve the problem preceded by many centuries the invention of the balloon, by which alone thus far the art of aërial navigation is practicable; and, like the pursuit of that other *ignis fatuus*, perpetual motion, the search for the solution of the flying-machine problem has been barren of results. Figure 10 (*pl.* 60) represents the appearance of one of the numberless extravagant and grotesque designs that have been prepared to solve the difficult problem of a flying-machine.

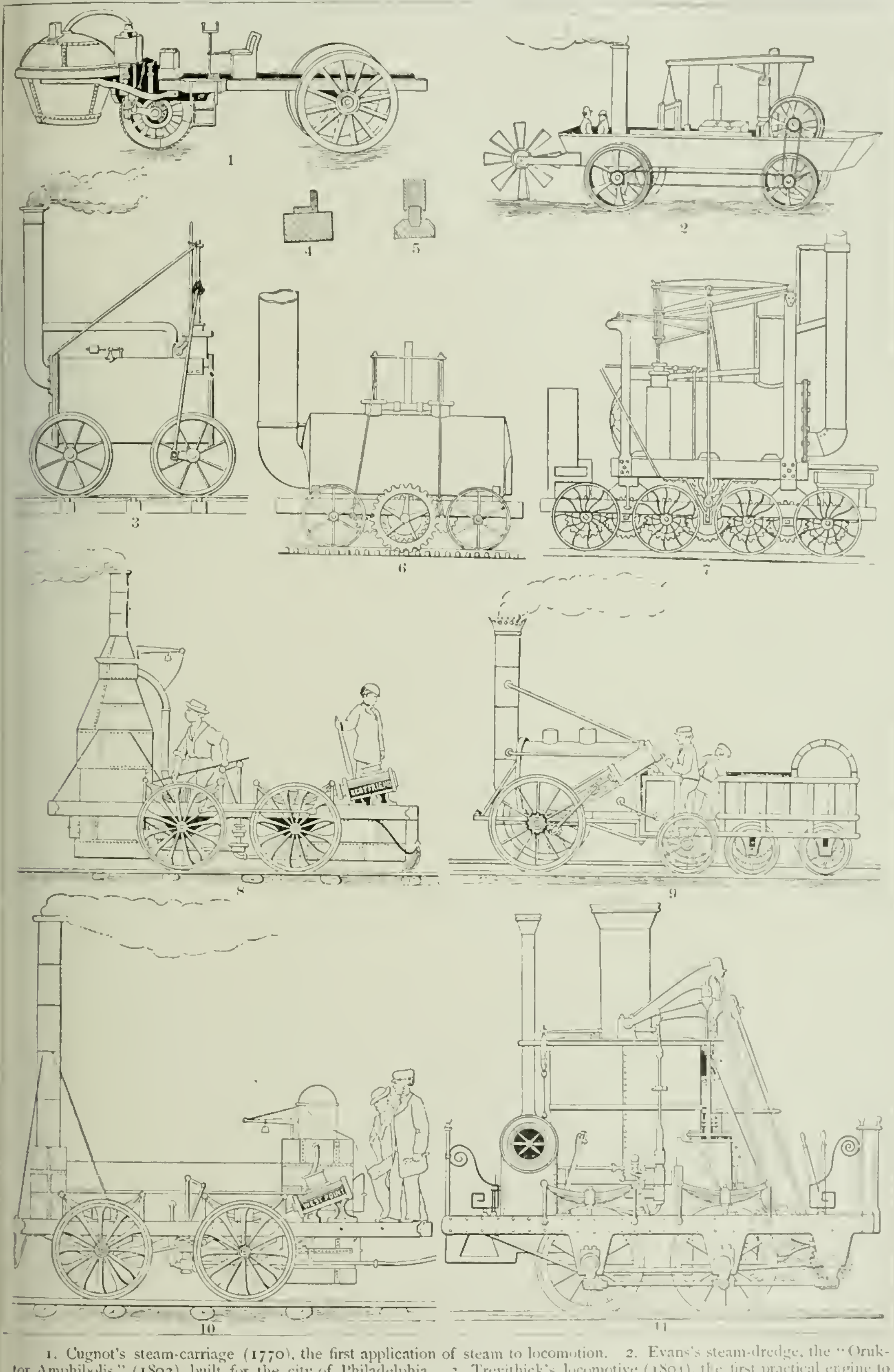
A volume might be written descriptive of the multitude of devices that have been proposed to accomplish this object, but the only thought they would awaken in the mind of the man of science would be one of regret at the exhibition of an amazing amount of ingenuity expended uselessly. We may, therefore, conclude this subject by summarizing the views of a recent writer, Professor Joseph le Conte, who has given the subject of the flying-machine a masterly review. This author, after pointing out the admirable adaptation of the structure of the bird—which has made this animal the incomparable model of a "flying-machine"—argues from the fact that since the animal body, considered as a machine, is twice as effective as the best Cornish engine, we cannot hope to devise a piece of mechanism which for the same weight of machine, fuel, and directing brain will be half as effective as that of the bird. Le Conte lays special stress on the fact that in perfecting her flying-machine (the bird) Nature has taught us that there is a low limit of weight (about fifty pounds) beyond which it is impossible for an animal to fly—a limit which Nature with her utmost effort has failed to pass. A prodigious advantage which the natural has over the artificial machine, as he ingeniously points out, is this: "The flying animal is its own engineer; the flying-machine must carry its engineer. The directing engineer (the brain) in the former is perhaps an ounce; in the latter it is a hundred and fifty pounds. The smallest possible weight of a flying-machine, with its necessary fuel and engineer, even without freight and passengers, could not be less than three hundred or four hundred pounds." From these considerations, which appear to be reasonable and sound, Le Conte concludes that a true flying-machine, self-raising, self-sustaining, and self-propelling, is physically impossible.



1. Cross-section of a timber causeway. 2. Cross-section of a plank road. 3. Half cross-section of Tresaguet's system of a stone road-bed. 4. Half cross-section of a macadamized road-bed. 5, 6. Sections of stone-block pavement. 7. Half cross-section of a tile pavement. 8. Half plan of the Belgian-block system of stone pavement. 9. Section of asphalt pavement. 10. Half section, 11 Plan, of stone-block pavement on streets with car-tracks. 12. Half section, 13. Plan, of cast-iron pavement at one time laid in New York City. 14, 15. Half cross-sections of stone-block pavement on streets with car-tracks. 16. Plan, 17. Section, of a cast-iron cellular pavement. 18. Longitudinal section, 19 Plan, of the Blake stone-crusher. 20. Longitudinal section of Augustin's gravel-screen. 21 Elevation, 22 Plan, of Bouillant's open-cylinder road-roller 23. Closed cylinder road-roller with double tongue 24. Aveling's steam road-roller 25. Elevation, 26. Plan, of a hand street-sweeper. 27. Elevation, 28. Brush, of a rotary sweeper used on the streets of Paris. 29. Longitudinal view of a street mud-scraper. 30. German street-sprinkling device. 31 Elevated street-crossing (erected in 1868, across Broadway, at Fulton street, New York City). 32-37 Running-gear of a heavy wagon; 32. Side elevation, 33. Half plan, 34. Half section, of front axle with wheel. 35. Half section of rear axle with wheel. 36. Spoke-fastening in hub and felly, and cross-section of spoke. 37. Spoke. 38. English farm-wagon. 39. Craven barouche, or half chaise, with C-springs. 40. Carriage platform-spring.



1. Block pavement. 2. Rubble pavement. 3. Longitudinal section of street sweeping machine with circular brush. 4. Longitudinal section of street sweeping machine with endless belt and brushes. 5. Modern heavy express-wagon. 6. Modern freight wagon. 7. Heavy wagon springs. 8. English carriage of the seventeenth century. 9. Extension-front brougham. 10. American "rockaway." 11. American "buggy." 12. Landaulette. 13. Cabriolet. 14. American "surrey." 15. American "phaeton."



1. Cugnot's steam-carriage (1770), the first application of steam to locomotion. 2. Evans's steam-dredge, the "Oruktor Amphibolis" (1802), built for the city of Philadelphia. 3. Trevithick's locomotive (1804), the first practical engine to run on rails, built for the railway at Pen-y-darran, Wales. 4. Carr's cast iron rail with upright flange (1776). 5. Wyatt's cast-iron edge-rail with the Jessop chair (1789). 6. Blenkinsop's tramway locomotive with spur wheels working in racks (1811), built for a colliery railway between Leeds and Middletown. 7. Hedley's locomotive "Puffing Billy" (1813), built for the Wylam colliery (England), now in the British Patent Museum, London. 8. First American-built locomotive, the "Best Friend" (1830), for the Charleston and Hamburg Railroad. 9. Stephenson's locomotive, the "Rocket" (1829), built for the Manchester and Liverpool Railroad. 10. Second American-built locomotive, the "West Point" (1831). 11. The "Atlantic" (1832), the so-called "Grasshopper" locomotive operated by the Baltimore and Ohio Railroad.

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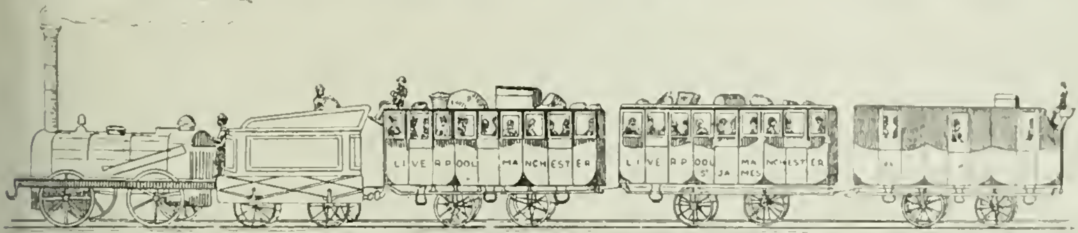

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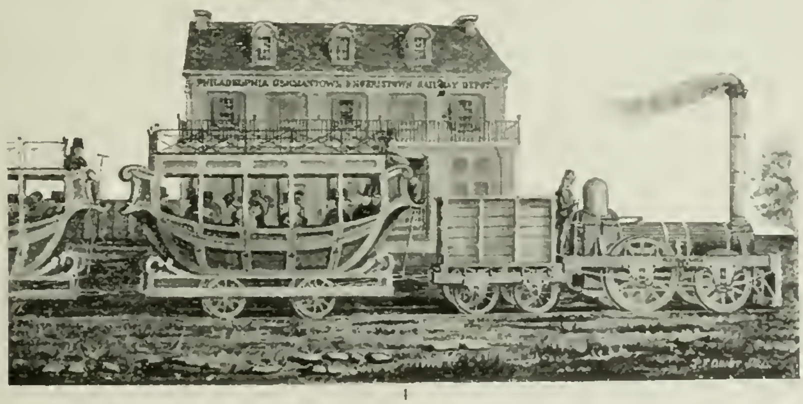

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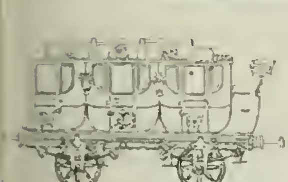

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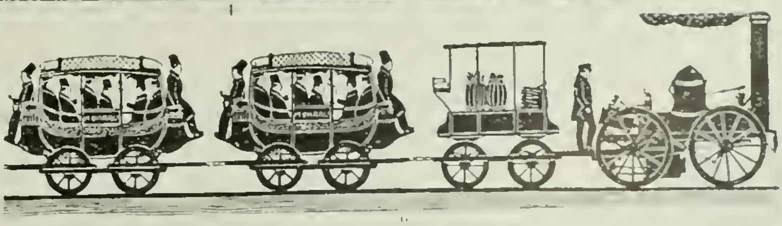

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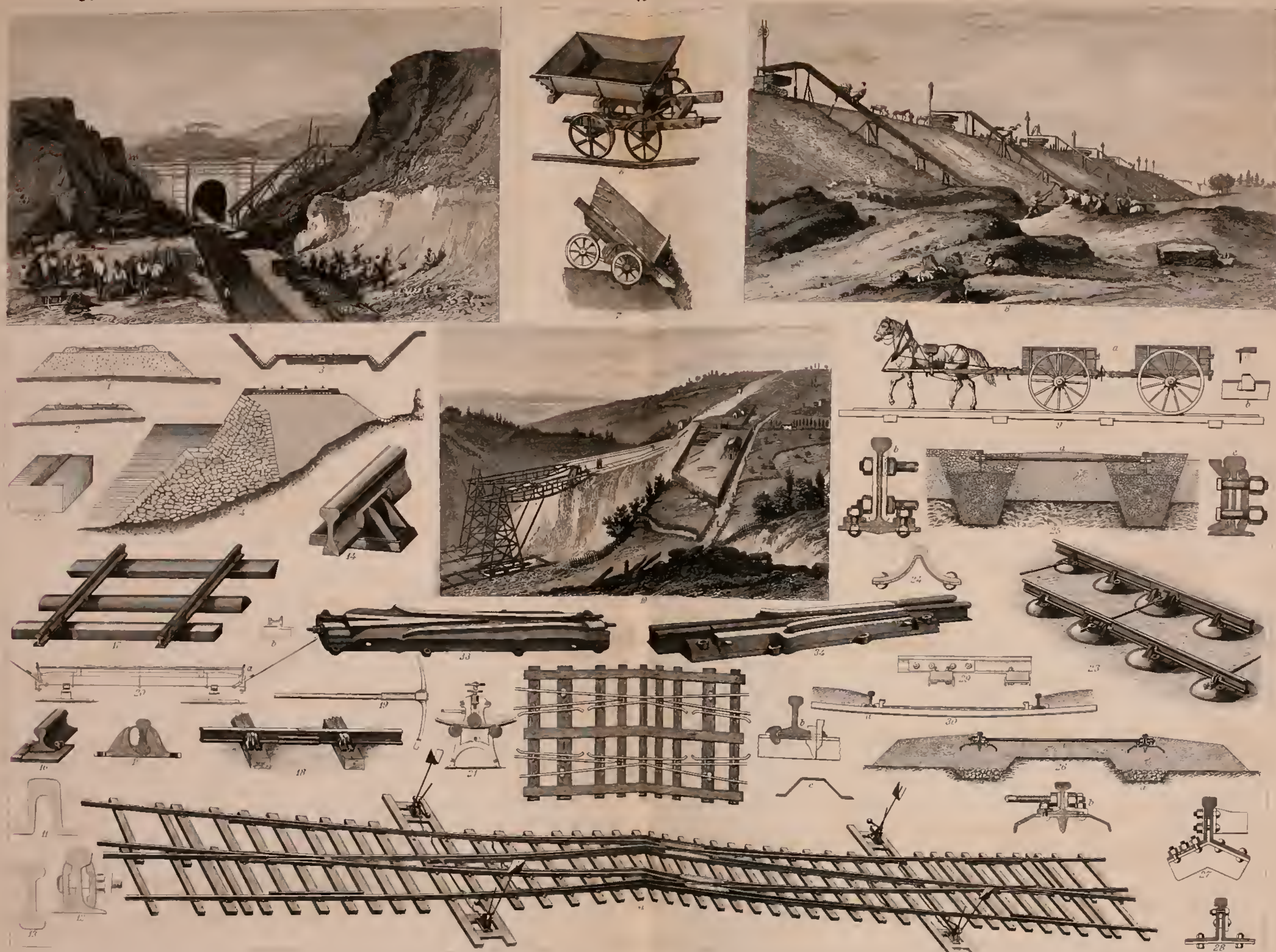
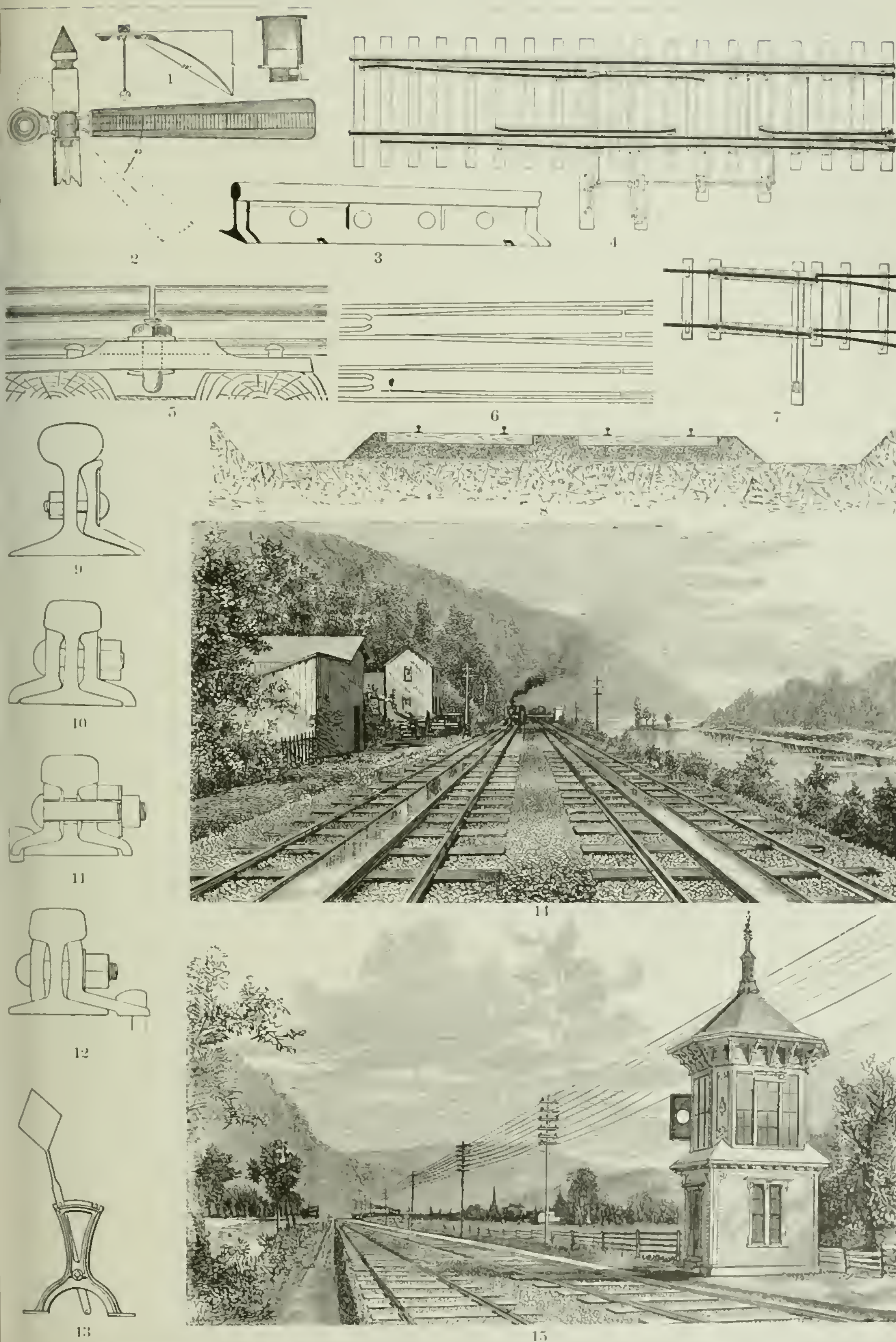
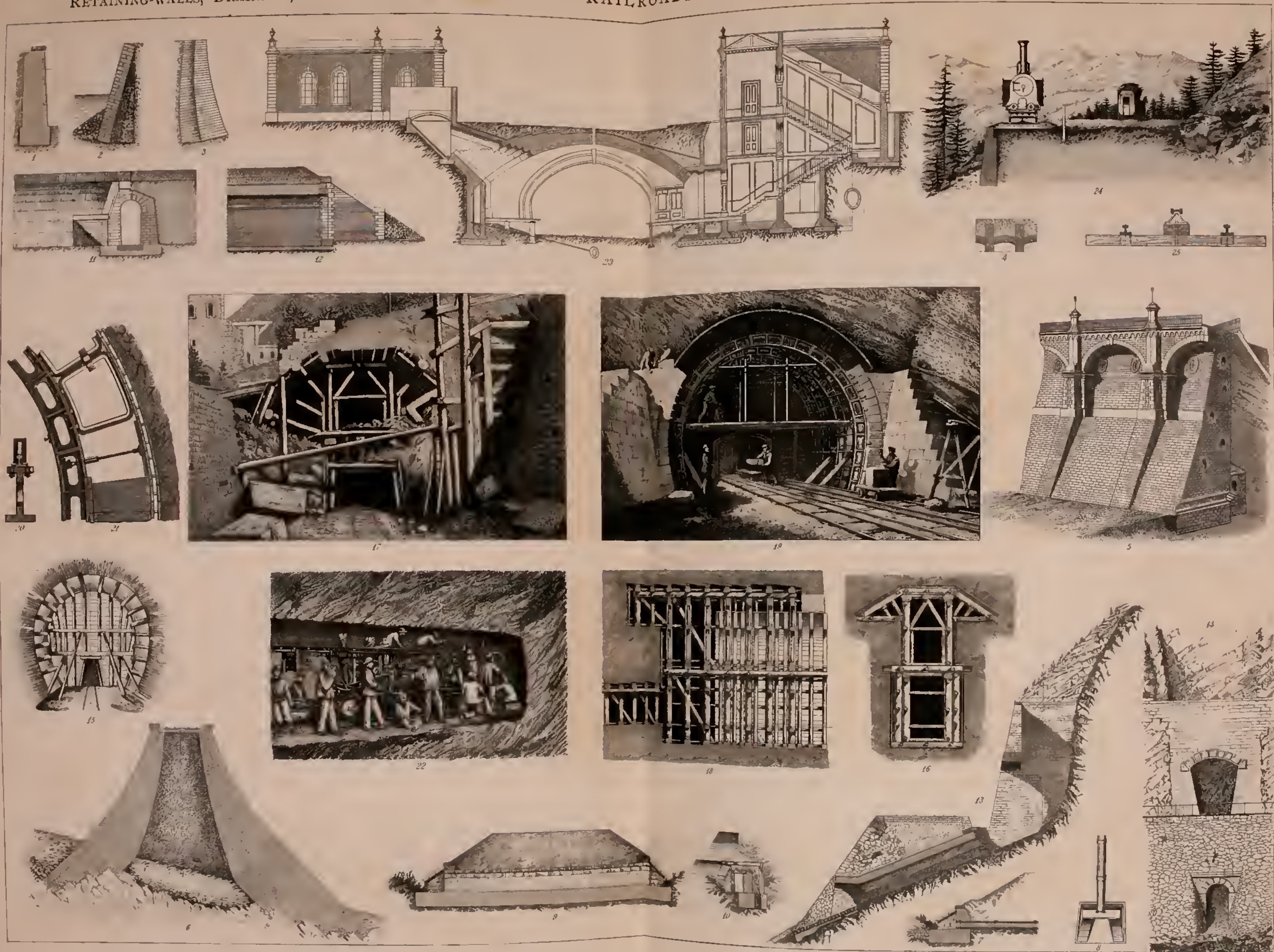
1. Early first-class train. 2. Early second-class train, of the Liverpool and Manchester Railroad (1829). 3. First assenger-train of the Stockton and Darlington Railroad (1825), drawn by Stephenson's "No. 1" locomotive. 4. First assenger-railway train in Pennsylvania (1832), operated on the Germantown and Norristown Railroad, and drawn by the "Old Ironsides" locomotive. 5. Early English railway-carriage: royal mail coach of the Liverpool and Birmingham Railway. 6. First passenger-railway train on the Mohawk and Hudson Railroad, New York (1831), drawn by the locomotive "John Bull."



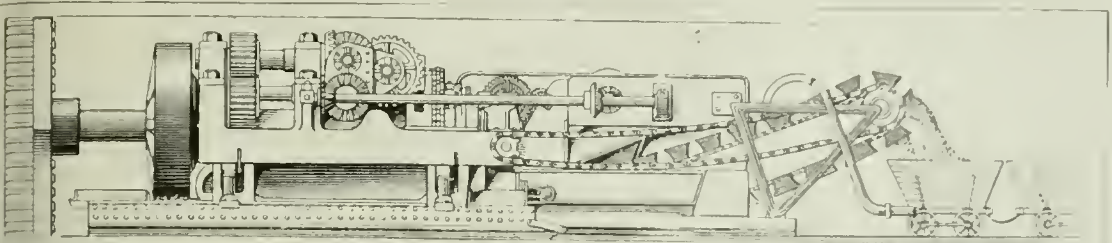
1–10. SUBSTRUCTURE: 1, 2. Road-bed embankments. 3. Road-bed with lateral ditches. 4 Stone retaining-wall of road-bed embankment. 5 Deep cutting in railroad construction. 6, 7. Tilting or dumping-cars. 8. Deep side-cutting for road-bed. 9a. Tram-cart, 9b. Section of stringer, 9c. Section of rail, of a temporary tramway. 10. Portable bridge used in building railroad embankments. 11–34. SUPERSTRUCTURE 11. Brunel or bridge rail. 12. Flange or T-rail, with fish-plate joint. 13. Double-headed chair-rail. 14. Single-headed rail and chair. 15. Double-headed rail and chair. 16. Flange rail and chair. 17. Flange rail with supported fish-plate joint, also showing different forms of cross-ties. 18 English chair-rail, with suspended fish-plate joint. 19 Tamping-pick. 20a. Longitudinal plan, 20b. End section, of a lever rail-bending machine. 21. Cross-section of a roller rail-bending machine. 22. Stone-block sill, with felt underlay for the rail. 23. Section of railway with Greaves's cast-iron sleepers. 24 Barlow rail. 25a. Cross-section of road-bed, 25b. Rail-section, showing fastenings of metallic cross-tie, and base, 25c. Section of rail with fish-plate joint, of the Hartwich metallic permanent way. 26a Section of road-bed, 26b. Section of metallic sleeper and rail, with metallic tie-rod, of Hilf's metallic permanent way. 27. Section of metallic permanent way of the Hanover State Railway. 28. Section of Schiffler's metallic permanent way. 29 Section of rail and wrought-iron cross-ties. 30a. Cross-section of road-bed, 30b Rail and fastening, 30c. Cross-section of metallic cross-tie, of Vautherin's system of track construction. 31. English system of railroad switches or turnouts. 32. Old system of railroad switches. 33, 34. Frog-plates for railroad switches.



1. Plan and lamp, 2. Elevation, of Koyl's parabolic semaphore signal. 3. Samson angle bar rail-joint (cross section, *fig* 9). 4. Wharton safety-switch. 5. Fisher bridge joint for rail. 6. Point switch. 7. Blunt end or stub switch. 8. Cross-section of road bed of the Pennsylvania Railroad. 9–12. Different forms of rail joints in use on American railways. 13. Switch-stand with target. 14. Section of track of the Pennsylvania Railroad, with track-tanks for supplying water to the locomotive while running. 15. Block signal tower of the Pennsylvania Railroad.



1-6. PROFILES OF RETAINING-WALLS: 1. Rectangular wall. 2. Trapeziform with inclined face. 3. Trapeziform with curved face. 4. English system of retaining-wall. 5. Abutment wall with discharging arches. 6. Curved retaining-wall of the Kulmbach inclined-plane railway, near Markt-Schorgast. 7-14. DRAINAGE: 7, 8, Cast-iron drain-pipes. 9. Longitudinal section, 10. Discharge end, of a covered drain of masonry. 11. Opening, 12. Longitudinal section, of arched culverts. 13. Cross-section, 14. Front section, of retaining-walls and drainage of steep side-cuttings. 15-23. TUNNELS: 15. Bulkhead of the Thames tunnel. 16, 17. Cross-sections, 18. Longitudinal section, of German systems of tunnel timbering. 19. Cross-section, 20, 21. Details, of Rziha's iron framework for tunnel construction. 22. Tunnel boring-machine operated by compressed air, used in the Mont Cenis tunnel. 23. Cross-section of an underground railway-tunnel and station in London. 24. Cross-section of roadway, 25. Rails, of Fell's system of mountain-railway construction.



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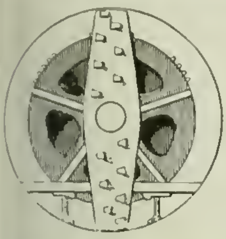

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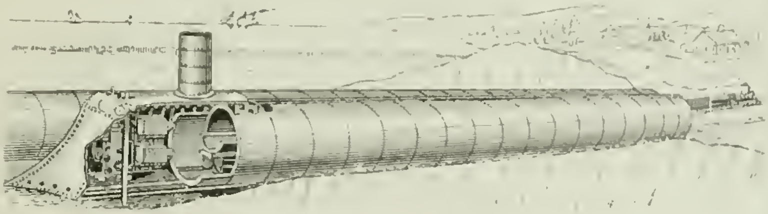

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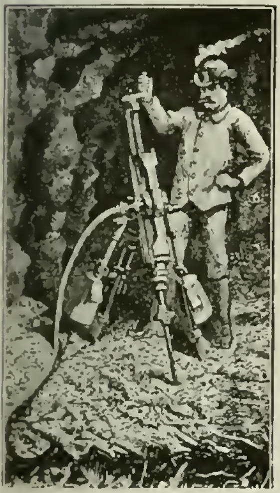

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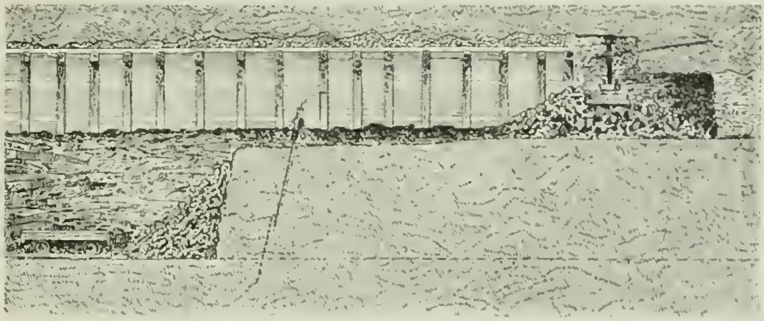

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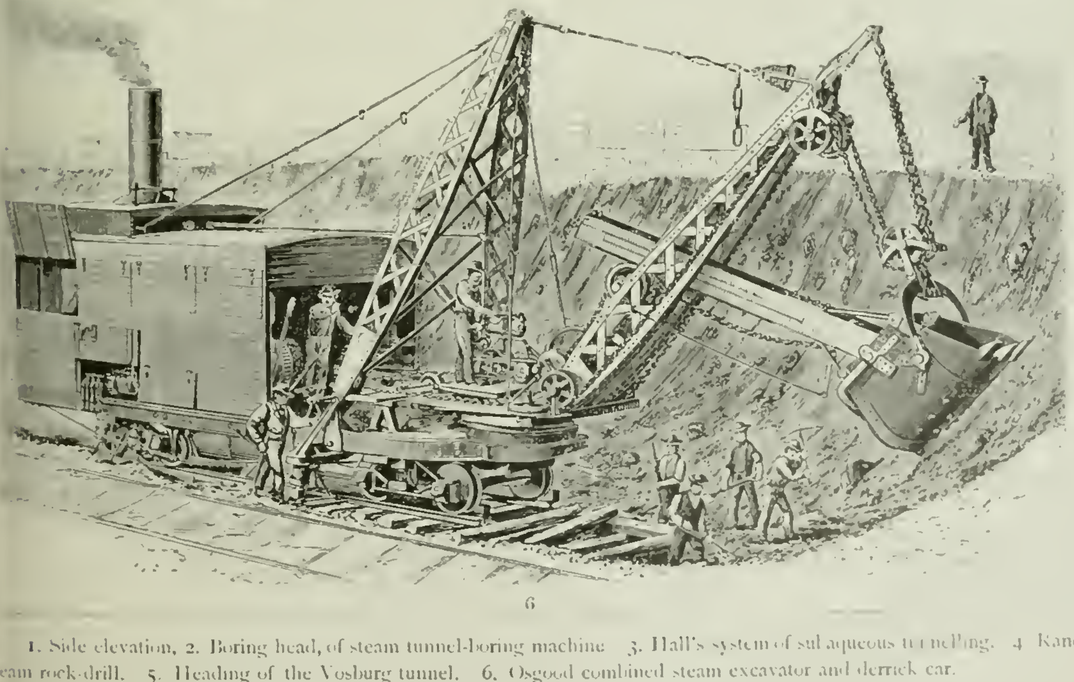

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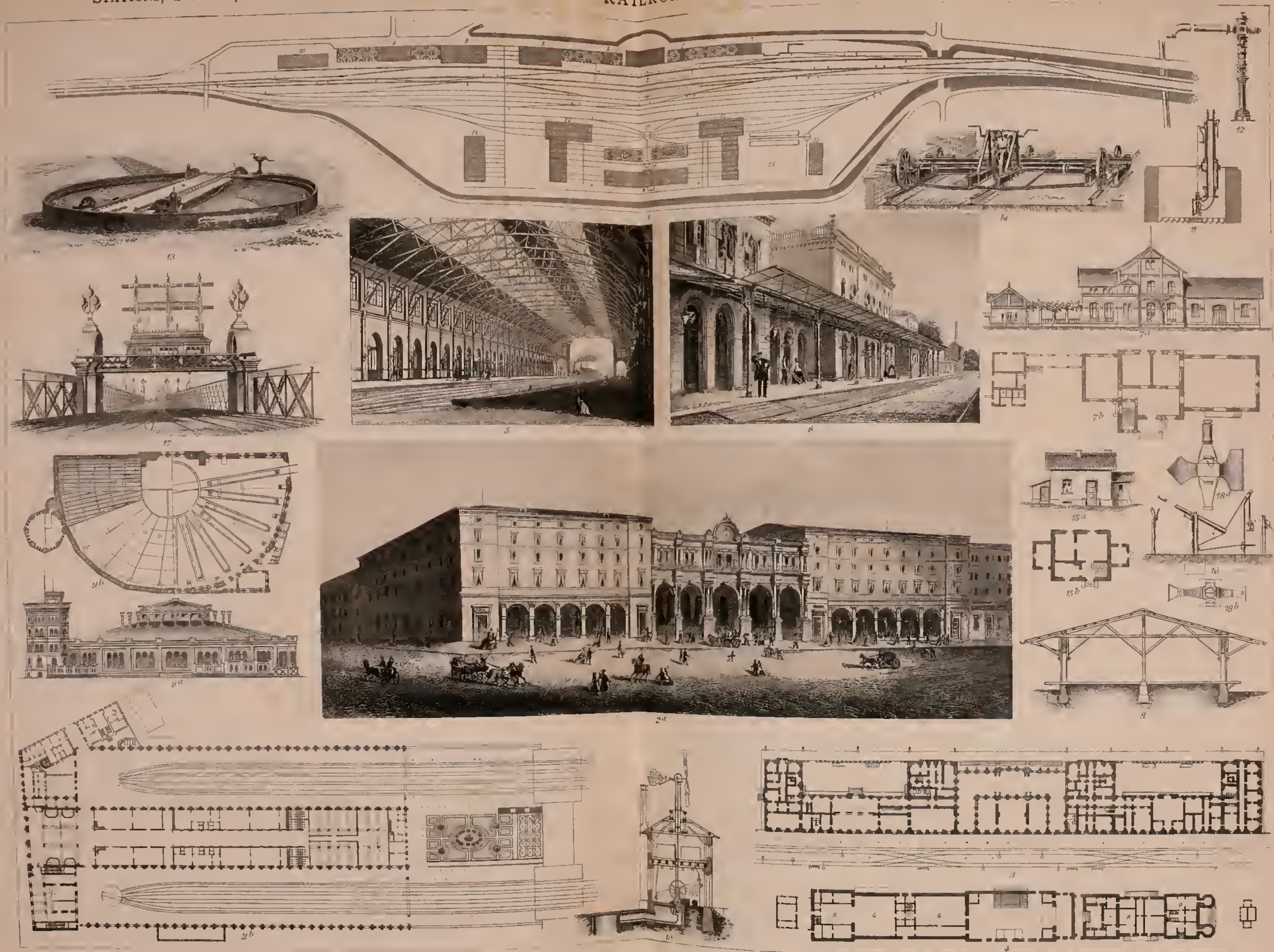
1. Side elevation, 2. Boring head, of steam tunnel-boring machine. 3. Hall's system of subaqueous tunnelling. 4. Rand steam rock-drill. 5. Heading of the Vosburg tunnel. 6. Osgood combined steam excavator and derrick car.



1. General plan of railway-station. 2*a*. Perspective, 2*b*. Ground-plan, of the railway-station at Stuttgart. 3. Ground-plan of the railway-station at Dresden of the Saxon-Bohemian railway. 4. Ground-plan of the terminal station at Görlitz. 5. Interior of the train-hall of the station at Stuttgart. 6. Façade of an intermediate station, with covered platform. 7*a*. Elevation, 7*b*. Ground-plan, of a small intermediate station. 8. Cross-sectional elevation of a freight-station. 9*a*. Elevation, 9*b*. Ground-plan, of a locomotive round-house. 10. Sectional elevation of a water-tank house. 11, 12. Crane connections for locomotive water-tanks at watering-stations. 13. Turntable. 14. Travelling-platform transfer-table. 15*a*. Elevatioo, 15*b*. Ground-plan, of a watchman's house on the Alteneck-Holzminden railway. 16. Barrier or safety-gate for railway-crossings. 17. Signal-house on the Charing Cross railway-bridge at London. 18*a*, *b*. Bender's system of railway-signals.

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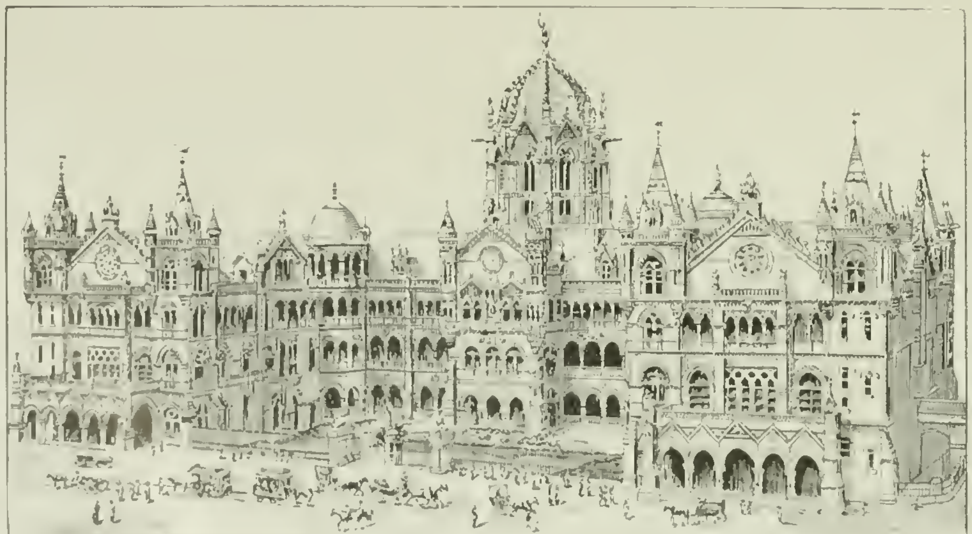

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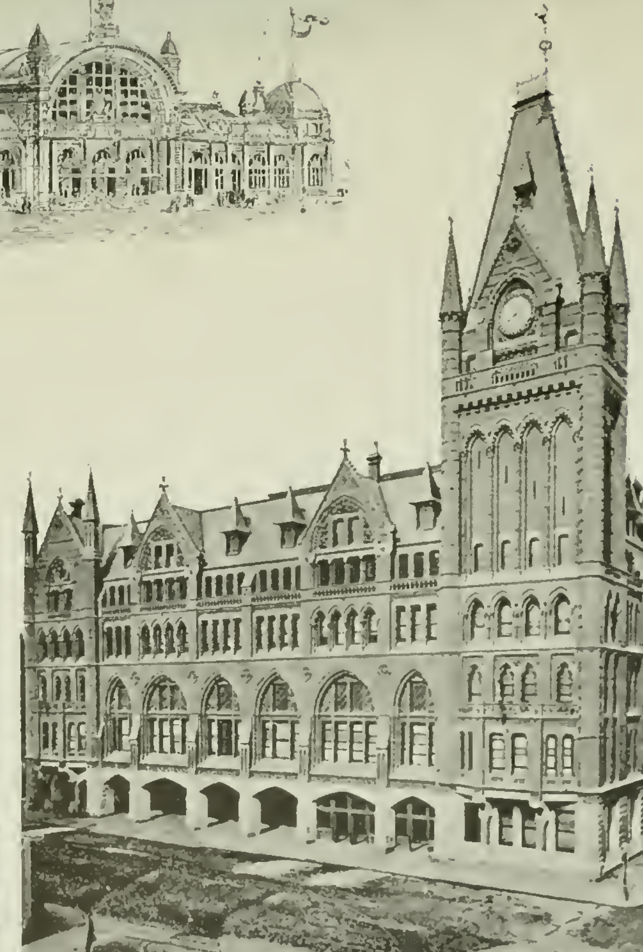

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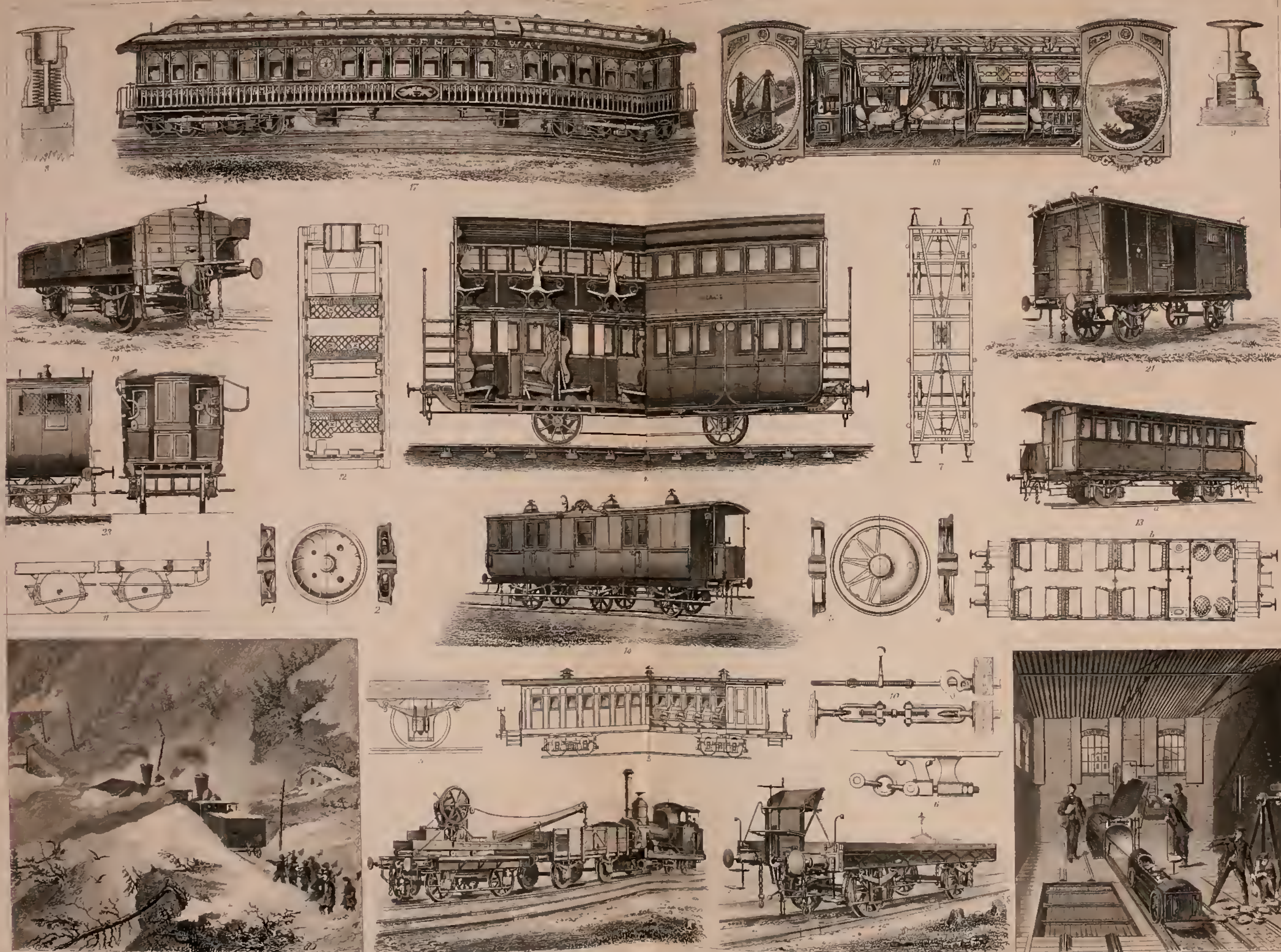
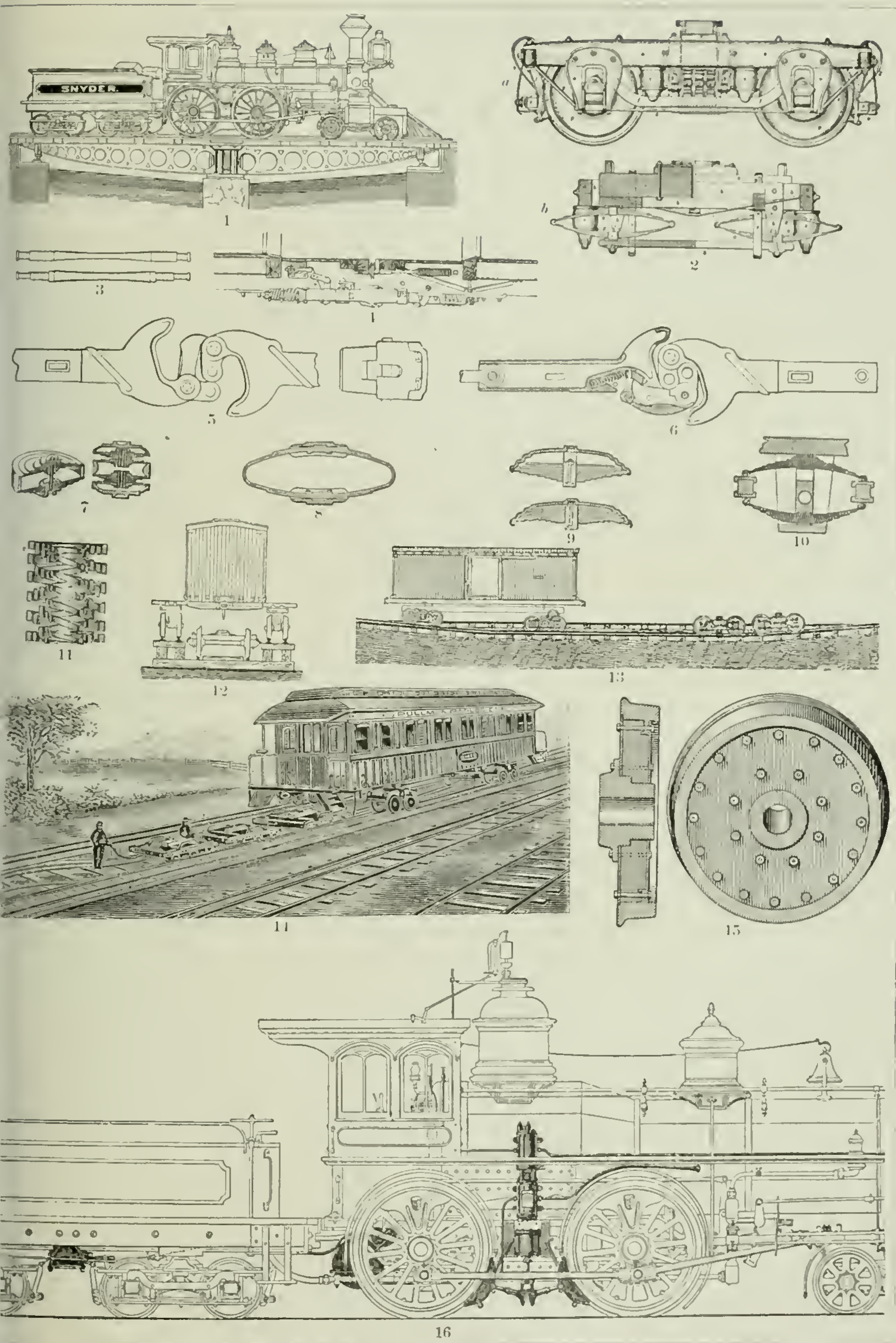
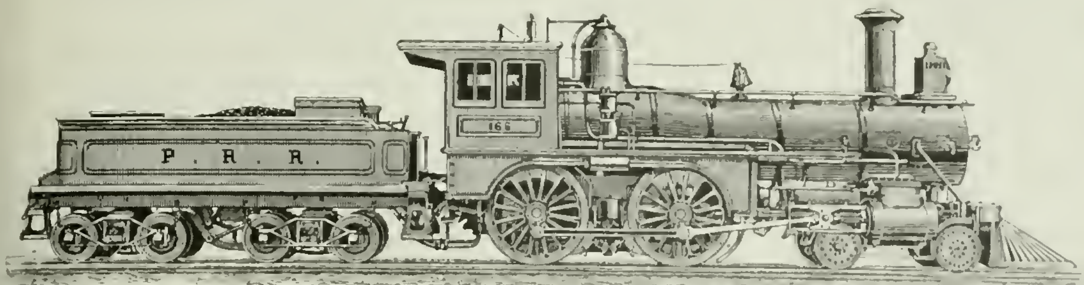
1. New Central Railway station at Frankfort-on-the-Main (Eggert). 2. Victoria Terminal Buildings of the Great Indian Peninsular Railway at Bombay, India (F. W. Stevens). 3. Terminal Passenger Station of the Pennsylvania Railroad at Philadelphia (Wilson Brothers & Co.).



1. Section and half vertical plan of the Washburn car-wheel. 2. Half vertical plan and section of a disk car-wheel. 3. Section and half vertical plan of a spoke car-wheel. 4. Half vertical plan and section of a cast-iron disk car-wheel. 5. German system of supporting car-bodies on springs attached to the axle-boxes. 6. Device for securing the ends of the springs to the car-body. 7. Plan of the under-framework of German railway-cars. 8, 9. Car-buffers in section, showing the springs. 10. Section and plan of a screw-coupling in use in Europe. 11. Hand-brake. 12. Plan of a German apartment-car. 13*a*. Perspective, 13*b*. Plan, of a four-wheeled intercommunicating composite car. 14. Six-wheeled composite compartment car with side entrances 15. Early form of an American car with four-wheeled trucks. 16. European four-wheeled two-story apartment-car. 17. Elevation, 18. Interior, of an American sleeping-car with eight-wheeled trucks. 19. German open freight-car. 20. German platform-car. 21 German covered freight-car. 22. Railway-crane for handling heavy loads. 23. Side elevation and end view of a German postal-car, showing automatic mail-bag-catching apparatus. 24. Snow-plough. 25. Car and tube of the pneumatic postal despatch between Euston Square Station and the District Post-office, London.



1. Kelly's cast-iron turn table. 2*a*. Side elevation, 2*b*. Cross section, of an American four wheeled car truck. 3. Car axles. 4. Attachment to car-body and connection, 5, 6. Action, of the Janney car coupler. 7-11. Various forms of American car-springs. 12. Cross-section at the bottom of the incline, 13. Longitudinal section, 14. Depressed track section, of the Ramsey car-transfer apparatus. 15. Section and vertical plan of the Allen paper car wheel. 16. Westinghouse automatic air-brake, showing the method of attachment to locomotive and tender.



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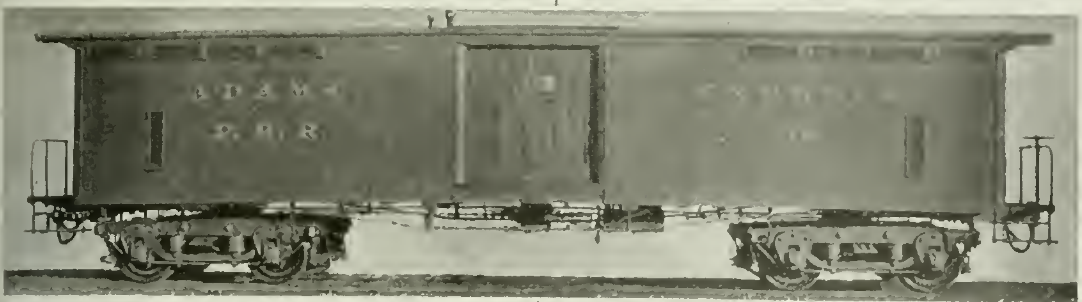

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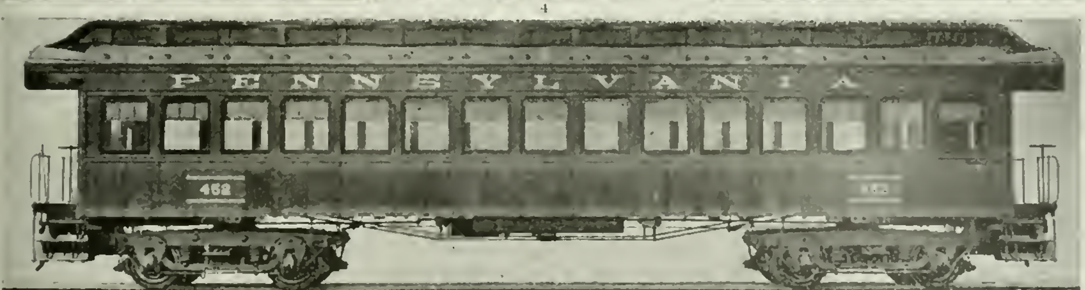

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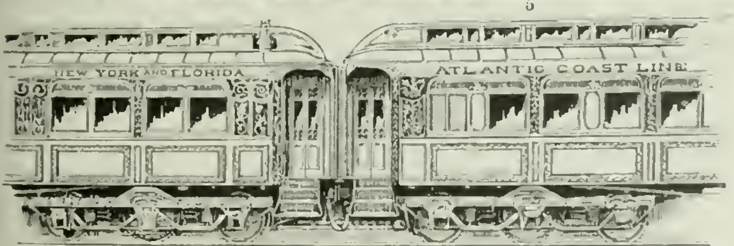

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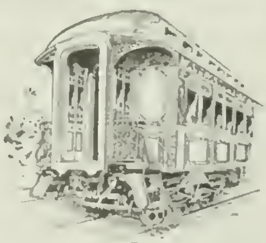

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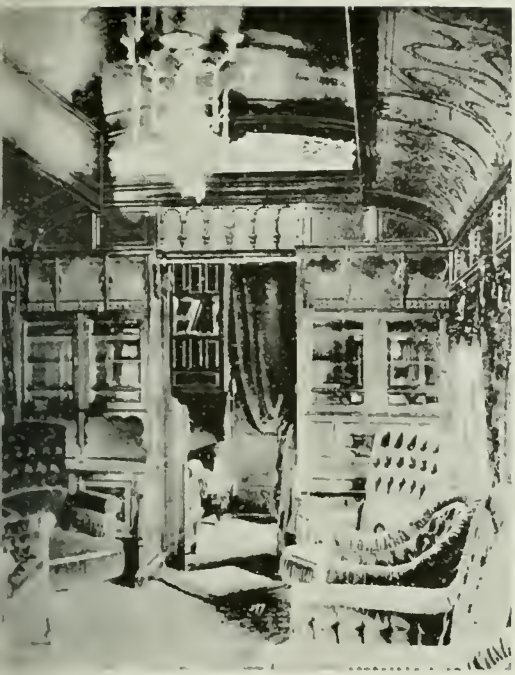
1. Standard locomotive, 2. Adams Express car, 3. United States post office car, 4. Standard parlor-car, 5. Standard passenger-car, in the service of the Pennsylvania Railroad. 6. Elevation, 7. Cross-section of the connection, of the Pullman vestibuled cars.



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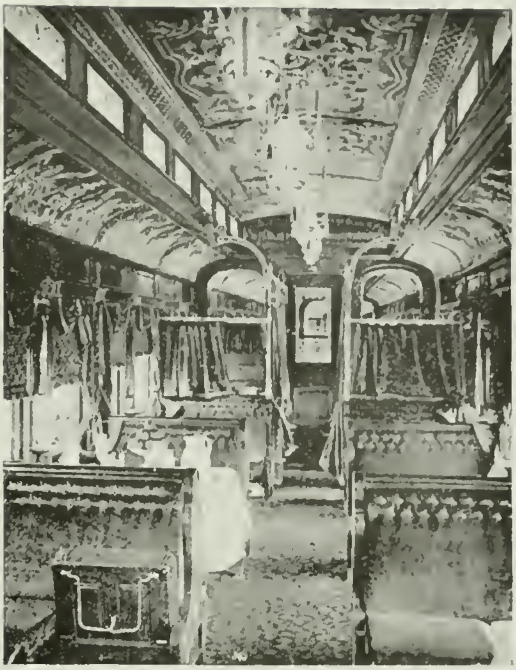

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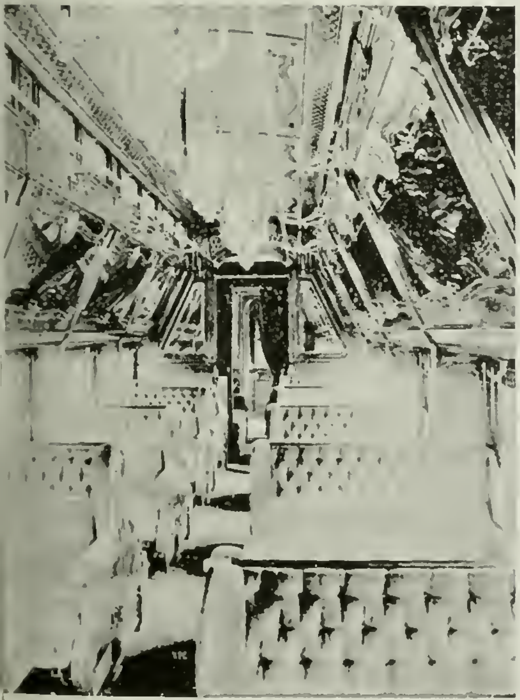

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1. Interior of a parlor-car, 2. Interior of a dining-car, 3. Interior of a sleeping-car, of the Pullman palace-car service. Interior of a combined parlor and sleeping-car of the Boston and Albany Railroad (Bruce Price architect).

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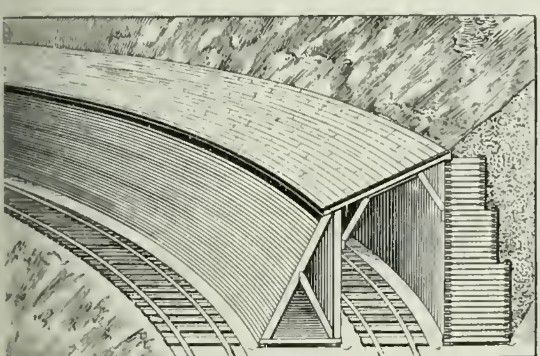

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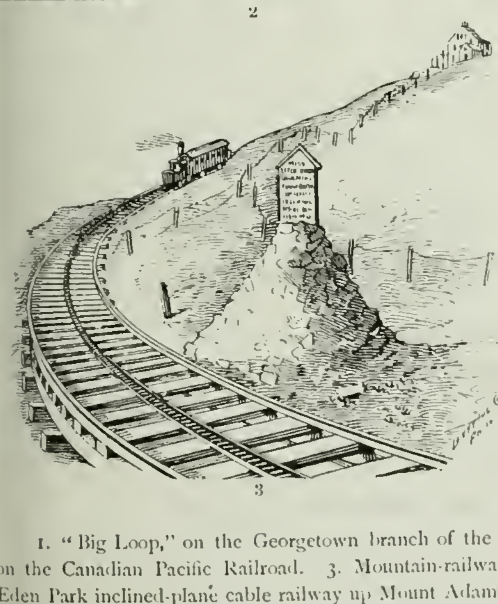

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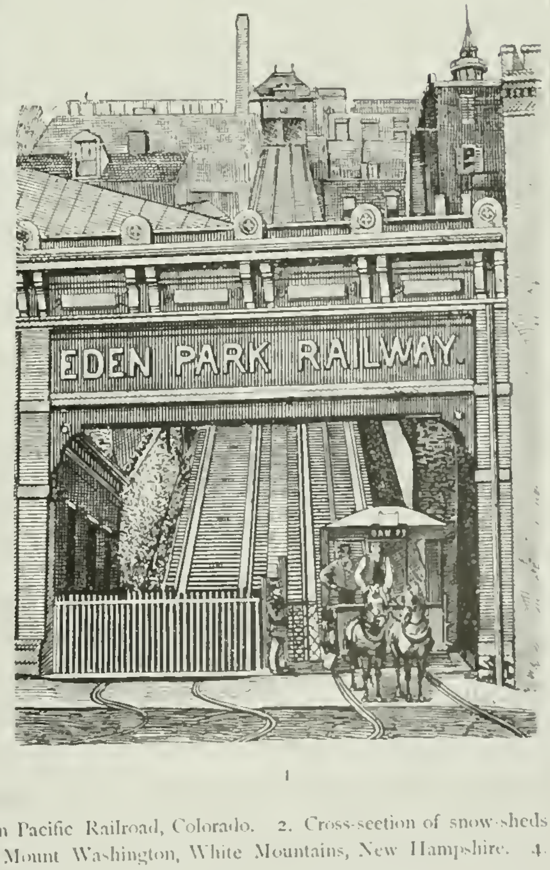

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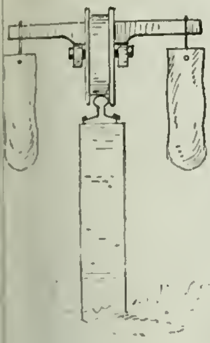
1. "Big Loop," on the Georgetown branch of the Union Pacific Railroad, Colorado. 2. Cross-section of snow-sheds on the Canadian Pacific Railroad. 3. Mountain-railway up Mount Washington, White Mountains, New Hampshire. 4. Eden Park inclined-plane cable railway up Mount Adams, at Cincinnati.



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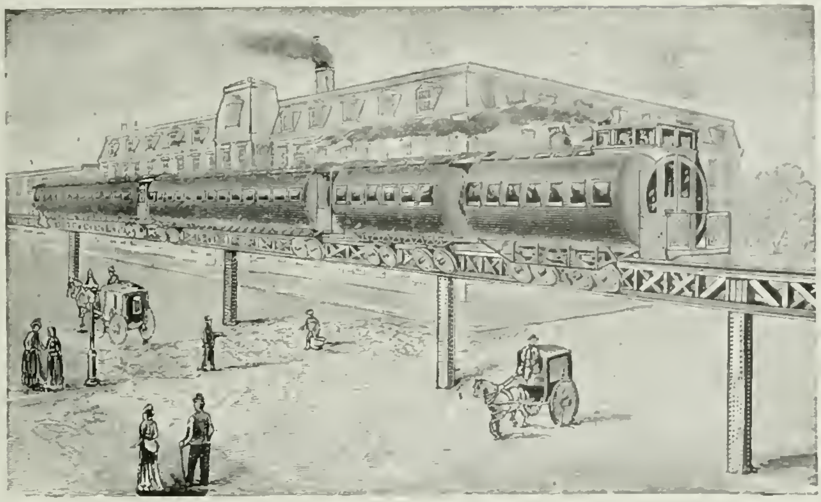

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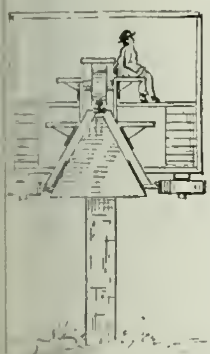

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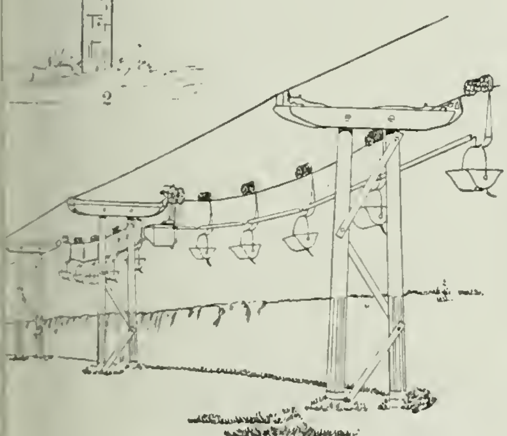

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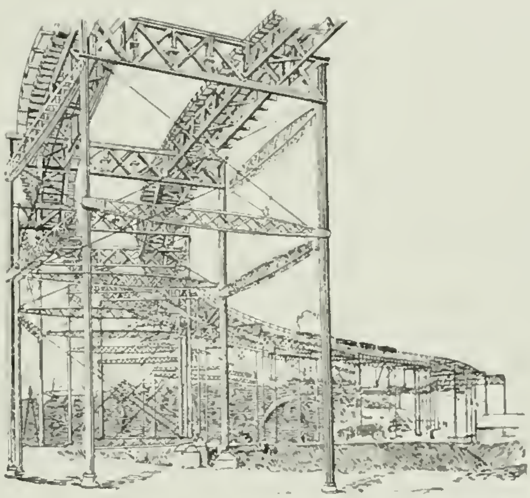

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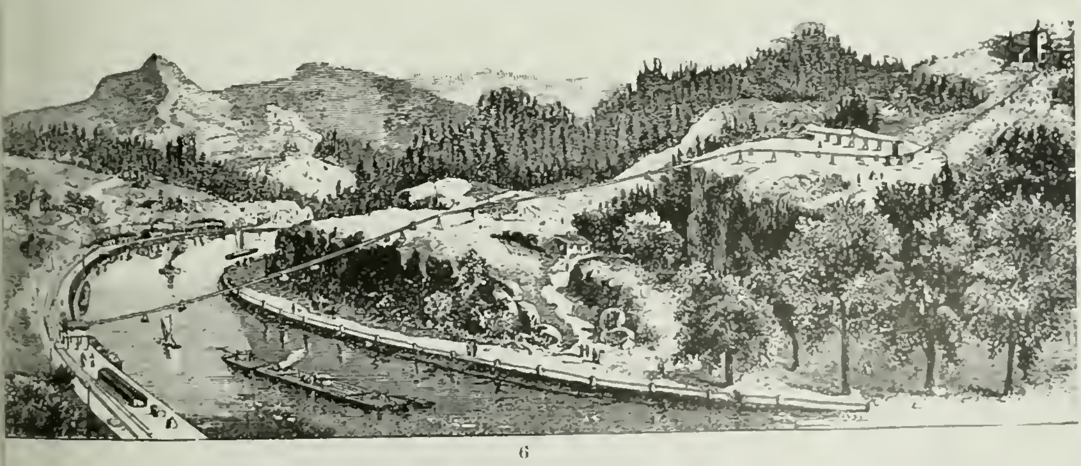

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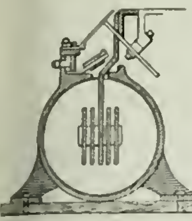
1. Primitive elevated-railway system of Palmer (1821). 2. Cross-section of General Stone's elevated-railway system, operation at the Centennial Exhibition at Philadelphia (1876). 3. Meigs elevated railway system, in operation at Bos-n. 4. Telpherage (electric) elevated railway system; telpher line at Glynde, England 5. Elevated-railway system in eration at New York City; section of the Metropolitan Elevated Railway. 6. Wire-rope transmission system of Bleichert.



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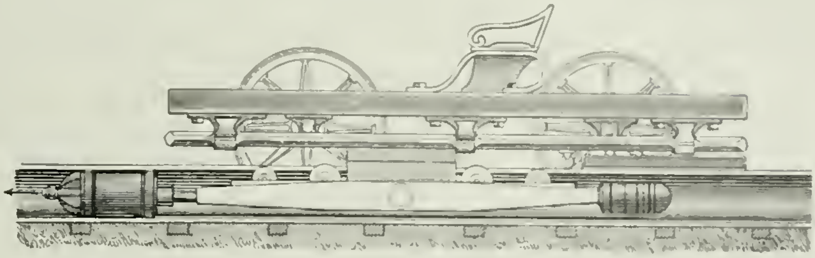

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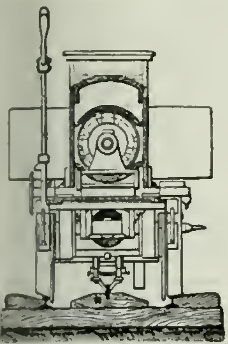

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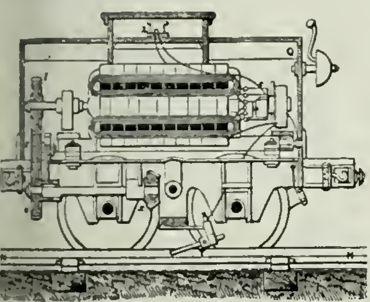

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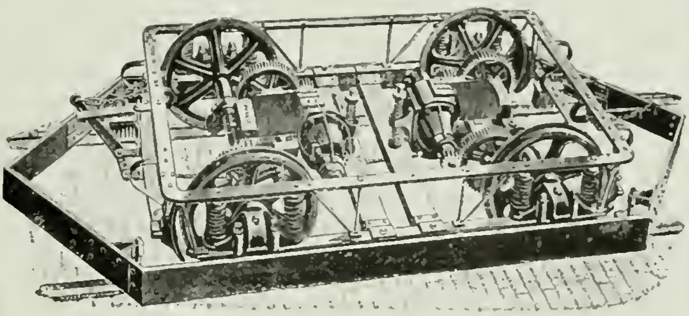

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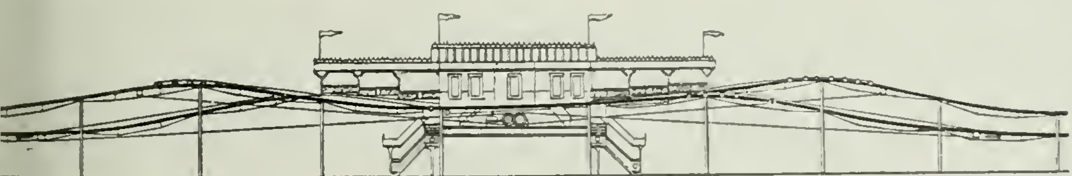

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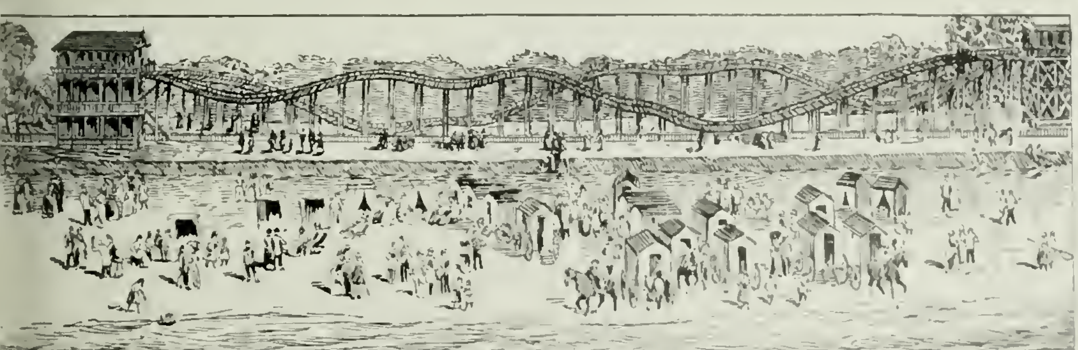
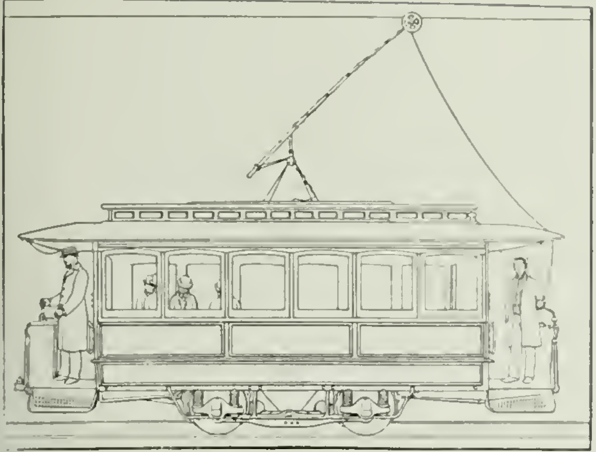


1. Cross-section of tube, 2. Longitudinal section of tube and car, of Clegg's atmospheric railway, operated between ingstown and Dalky, Ireland (1844). 3. Cross section, 4. Longitudinal section, of motor, 5. Motor and train, of Siemens's rst electric passenger-railway: experimental line on the grounds of the Munich Electrical Exhibition (1880). 6. Sprague lectric-motor truck. 7. Thompson's combined gravity and cable-railway system for rapid transit. 8. Thompson's switch-ack system: railway at Boulogne-sur-Mer, France.



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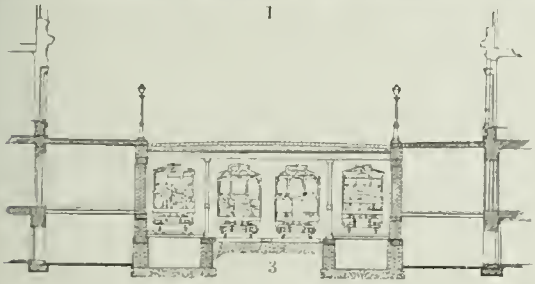

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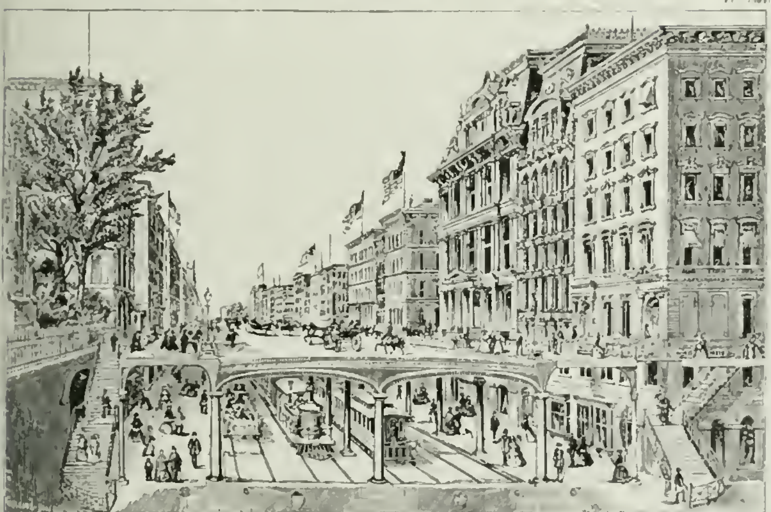

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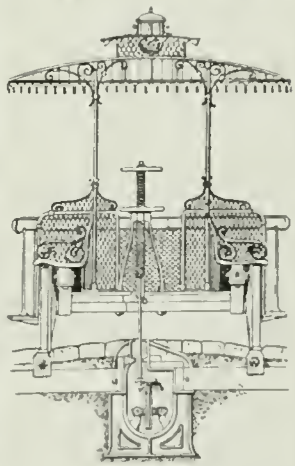

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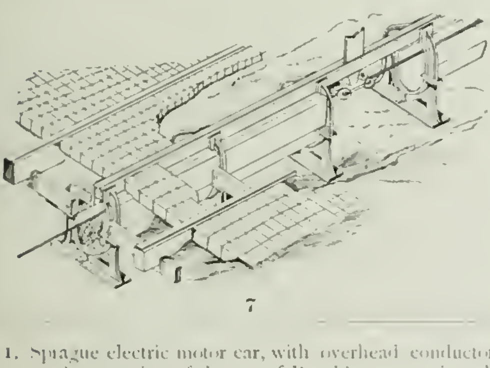

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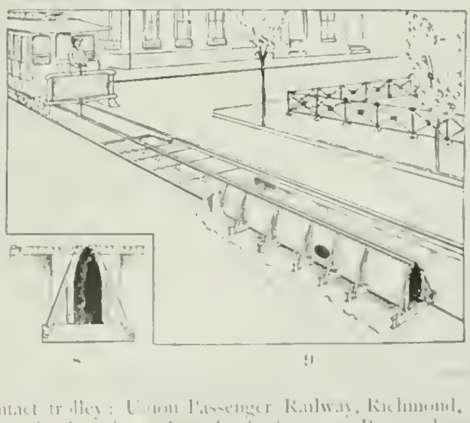

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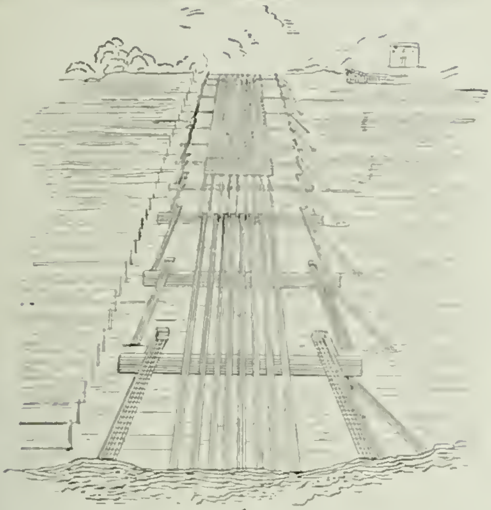
1. Sprague electric motor car, with overhead conductor and contact trolley: Union Passenger Railway, Richmond, Virginia. 2. Cross-section of the car of Beach's pneumatic railway (laid under Broadway, New York City). 3. Proposed system of underground railway for New York City. 4. Subway of the Fourth Avenue extension of the Harlem Railway, New York City. 5. Proposed arcade railway under Broadway, New York City. 6. Cross-section of car and tube, 7. Plan of the conduit, of the original cable railway, San Francisco (Hallidie's system). 8. Cross-section of tube, 9. Plan of the conduit, of the cable-railway system of the Philadelphia Traction Company.



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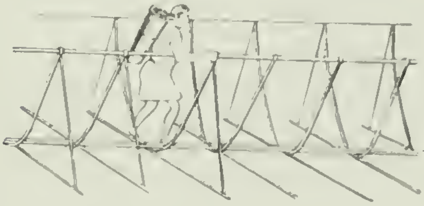

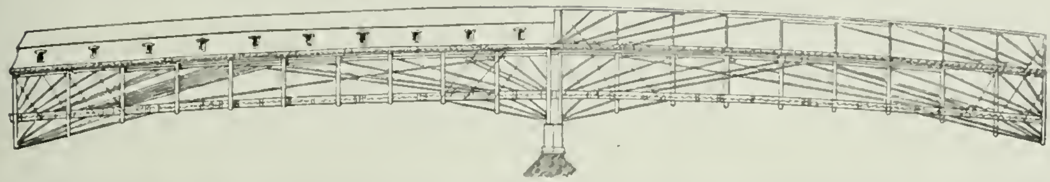

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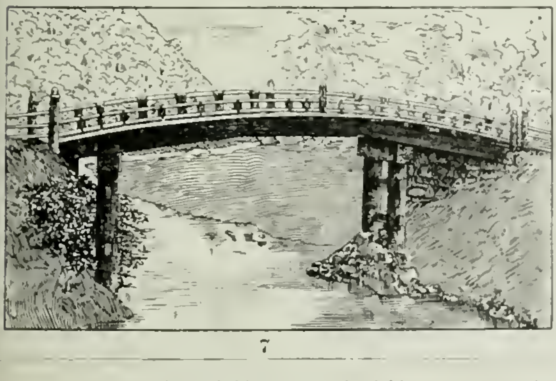

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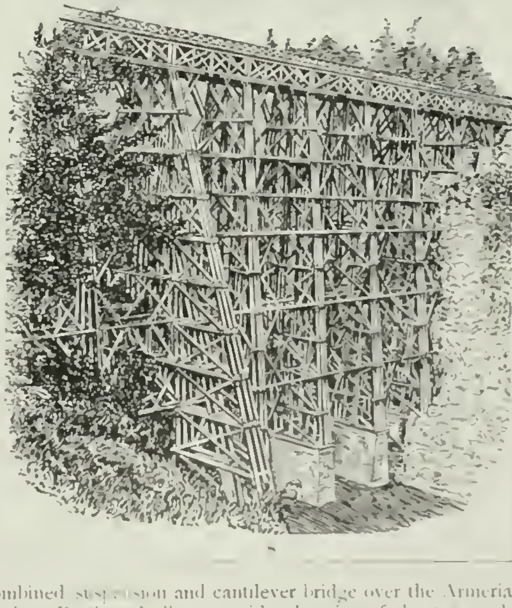

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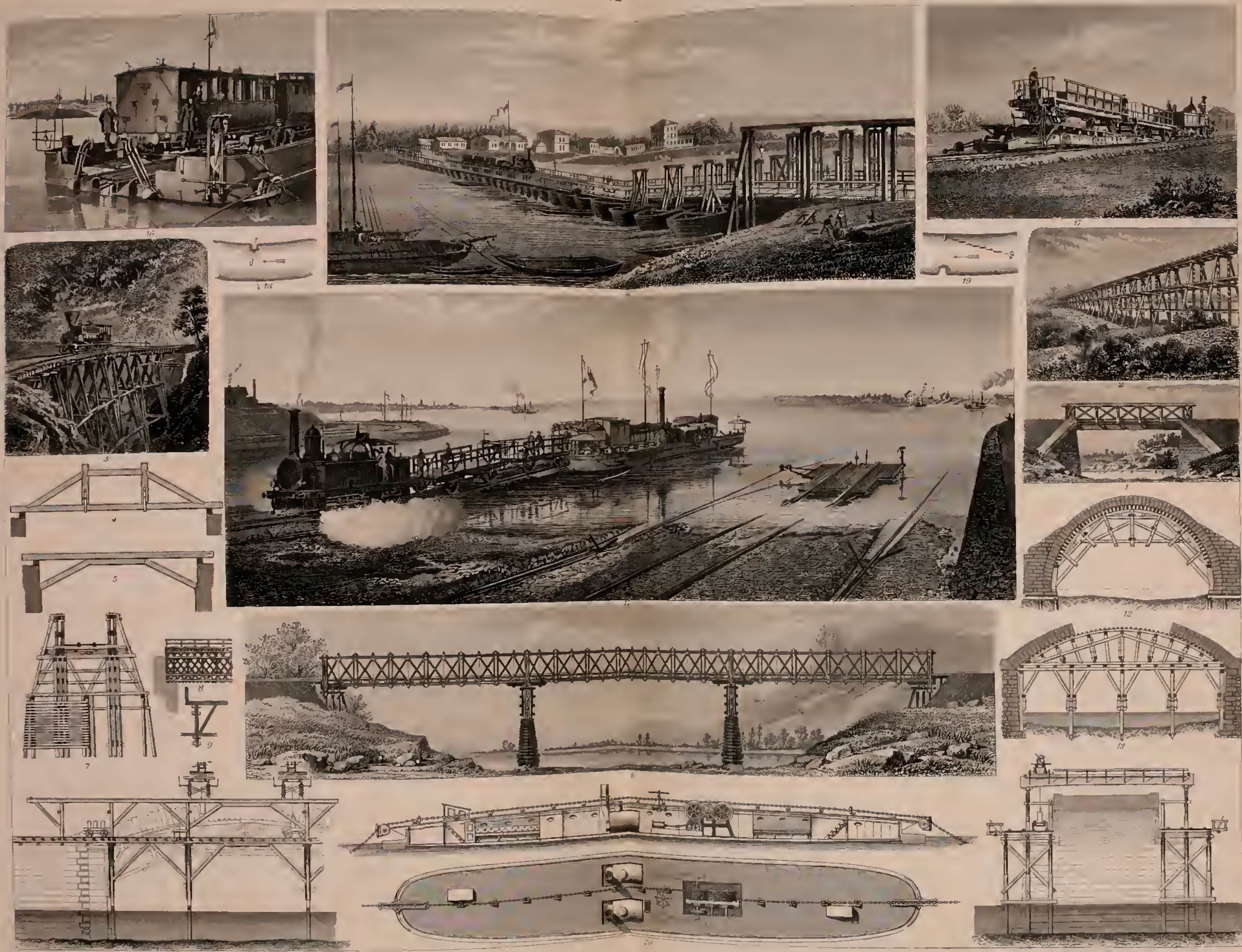
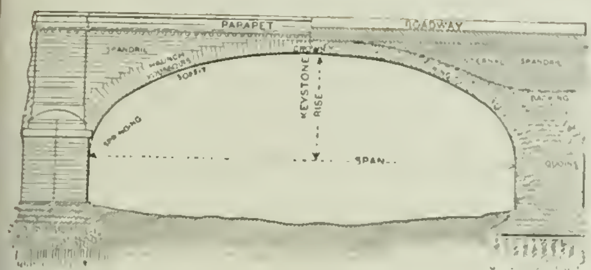
1. Cæsar's military bridge across the Rhine. 2. Primitive combined suspension and cantilever bridge over the Armeria River, Colima, Mexico. 3. Native suspension bridge across the river Runject, India. 4. Side elevation of the first arch and details of the second arch of a truss bridge over the Rhine at Schaffhausen (1757; Ulric Grubermann), burned by the French troops in 1799. 5. Elevation. 6. System of construction, of a "flying bridge" designed by Thomas Pope (1810) for an arched bridge across the North River, New York. 7. Japanese cantilever bridge at Nikko. 8. Old portage trestle bridge (1852) over the Genesee River on the New York, Lake Erie and Western Railroad (Silas Seymour, C. E.).



1. Wooden-girder bridge. 2, 3. Wooden-trestle railway-bridges. 4. Truss frame. 5. Strut frame. 6. Elevation, 7. Cross-section, of a Howe truss-girder railway-bridge with wooden piers and trestles. 8, 9. Sections of a Town lattice-truss bridge. 10. Elevation, 11. Cross-section, of arch construction and scaffolding, 12. Semicircular arch and centre, of a single-span stone bridge. 13. Segmental arch and centre of a single-span stone bridge. 14. Pontoon railway-bridge across the Rhine at Maxau. 15–17. Ferry of the Rhenish Railway between Rheinbausen and Hochfeld, Germany. 18. Plan of a cable ferry. 19. Plan of a "flying" ferry. 20. Elevation and plan of a chain-cable steam-towage ferry-boat.



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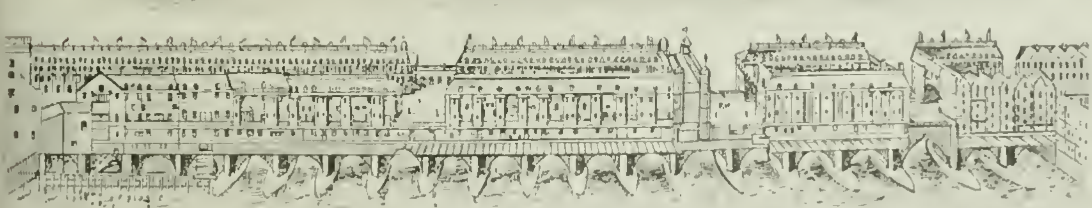

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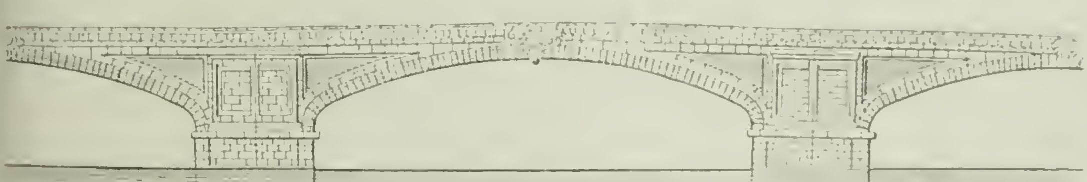

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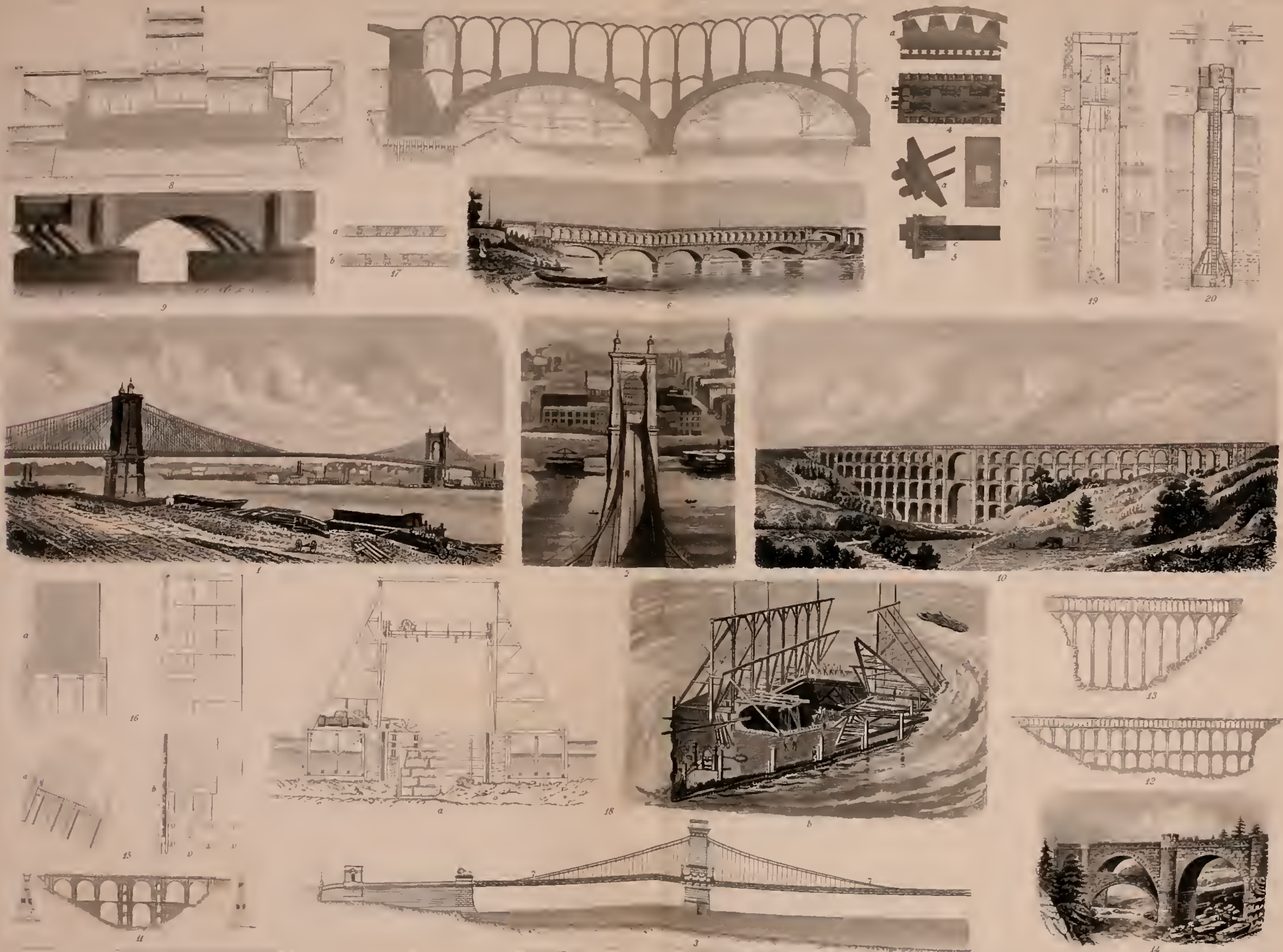
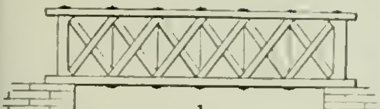
1. Details of construction of arched stone bridges. 2–7. Ancient and mediæval stone bridges: 2. Roman bridge at St. Chamas, France. 3. Triangular bridge at Croyland (fourteenth century) with three way pointed arches. 4. Old Bridge at Saintes, France (fourteenth century). 5. Chinese semicircular arch bridge. 6. Old London Bridge over the Thames (1700 A. D.). 7. Ponte della Trinita at Florence (1566), earliest flat arch bridge (Bartolommeo Ammanati).



1. Perspective, 2. Tower, of the suspension bridge (1867), over the Ohio River at Cincinnati (John A. Roebling, C. E.). 3. Half-section elevation of the suspension bridge (1819) over the Danube at Pesth-Ofen (T. Clark, C. E.). 4*a*. Cross-section, 4*b*. Plan, of a saddle-plate bearing for suspension bridges. 5*a–c*. Plates and fastenings of a chain suspension bridge. 6. Elevation, 7. Longitudinal section, showing details of construction, 8. Cross-section, of the Pont du Jour, an elliptical-arch bridge over the Seine at Paris. 9. Askew-arch bridge. 10. Perspective of the Göltzschthal Viaduct. 11. Elevation and cross-section of the Elsterthal Viaduct (1851) of the Saxon-Bavarian State Railway (R. Wilke, C. E., and H. Kell, C. E.). 12. Roquefavour Aqueduct over the Arc, on the canal from Durence to Marseilles, France (1841–1847). 13. Ancient aqueduct at Spoleto. 14. Calvine Viaduct near Blair-Athole, Perthshire, Scotland. 15*a*, 16*a*. Elevations, 15*b*, 16*b*. Plans, of pile foundations (grillage). 17*a*, *b*. Cross-section of sheet-piling. 18*a*. Cross-section, 18*b*. Perspective, of a floating caisson used for constructing the piers of the Victoria Bridge over the St. Lawrence River at Montreal. 19. Triger's plenum process, 20. Modified plenum process, for subaqueous foundations.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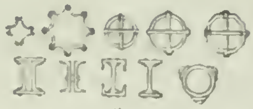
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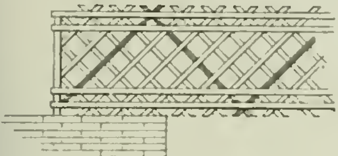
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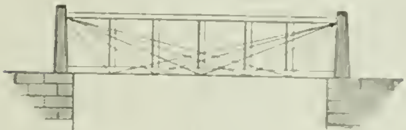
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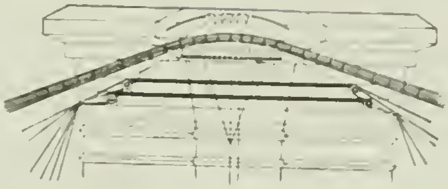
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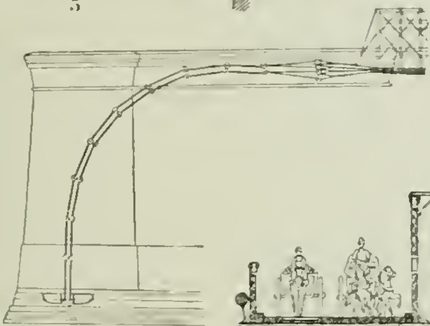
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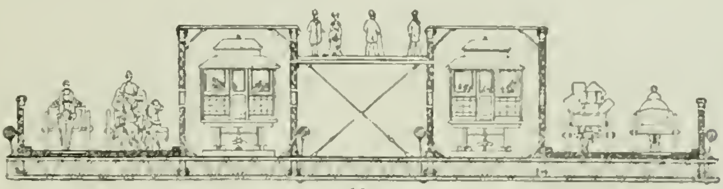
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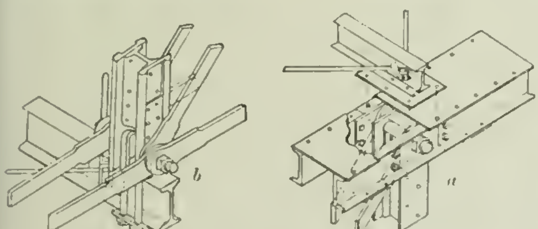

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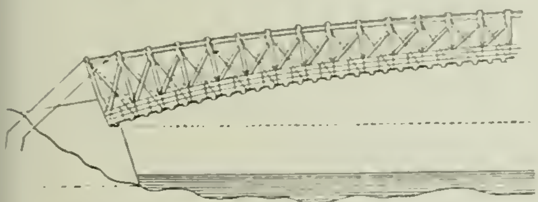
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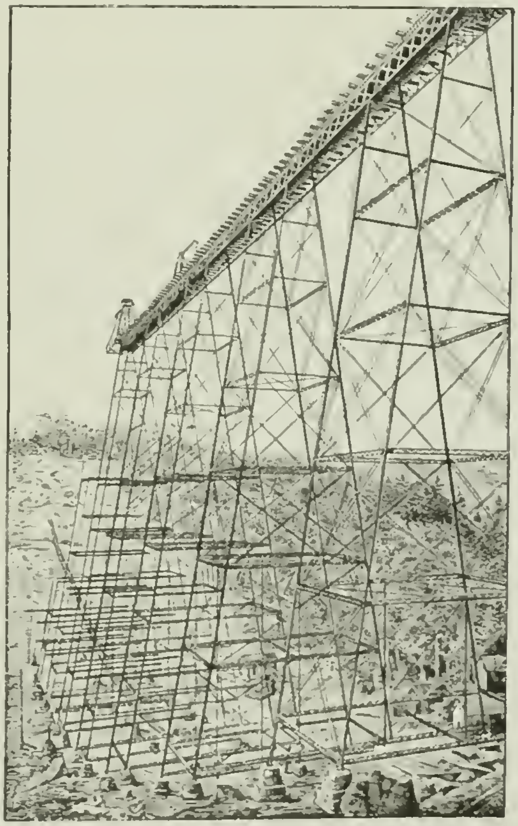
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1–5. Forms of bridge trusses: 1. Howe truss, 2. Town lattice truss, 3. Warren truss, 4. Fink truss, 5. Bollman truss. 6. Cross sections of Keystone Bridge columns. 7. Cross-sections of Phœnix wrought iron columns. 8. Pin connection and eye bar of an American iron bridge. 9. Anchorage, 10. Saddle plate, 11. Cross section, 12. Entrance, of the East River Suspension Bridge, New York. 13. Pin connections, *a* upper, and *b* lower, chord, of an American iron bridge (American Bridge Company). 14. Half-section elevation of the arch-truss bridge across the Schuylkill River at Philadelphia. (See *pl.* 44.) 15. New iron-trestle bridge over the Kinzua Gorge, in process of construction. (See *pl.* 46.)

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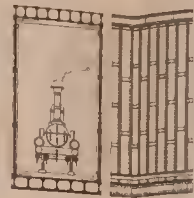

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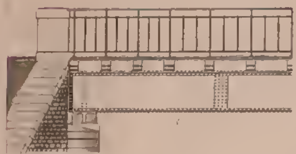

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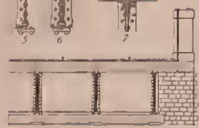

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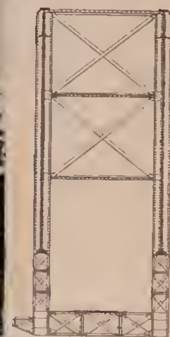

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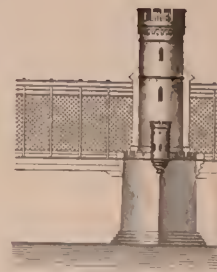

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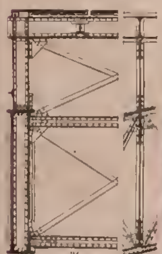

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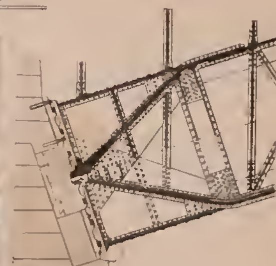

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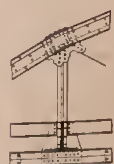

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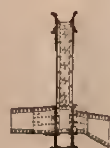

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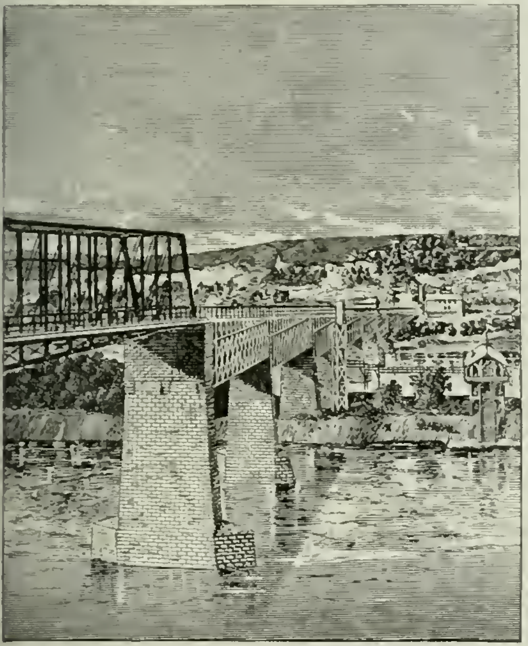

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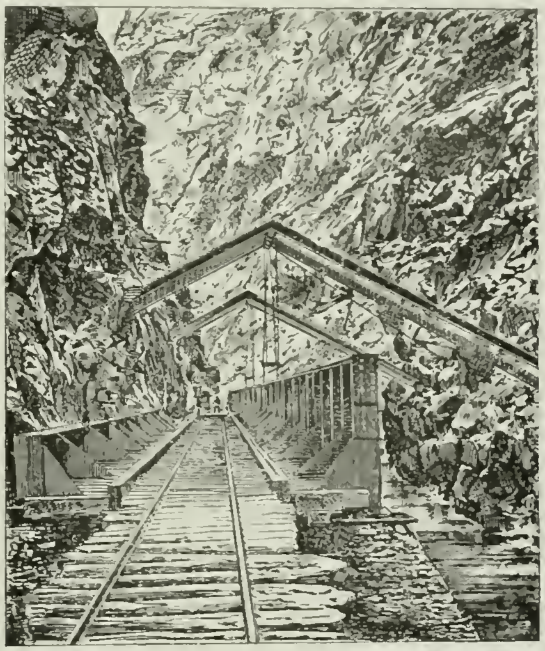

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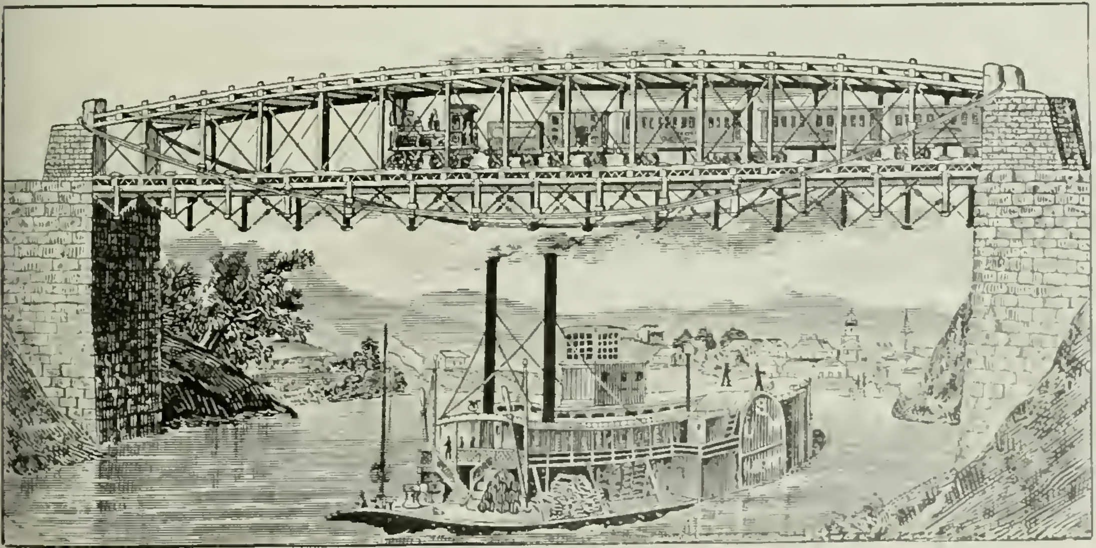

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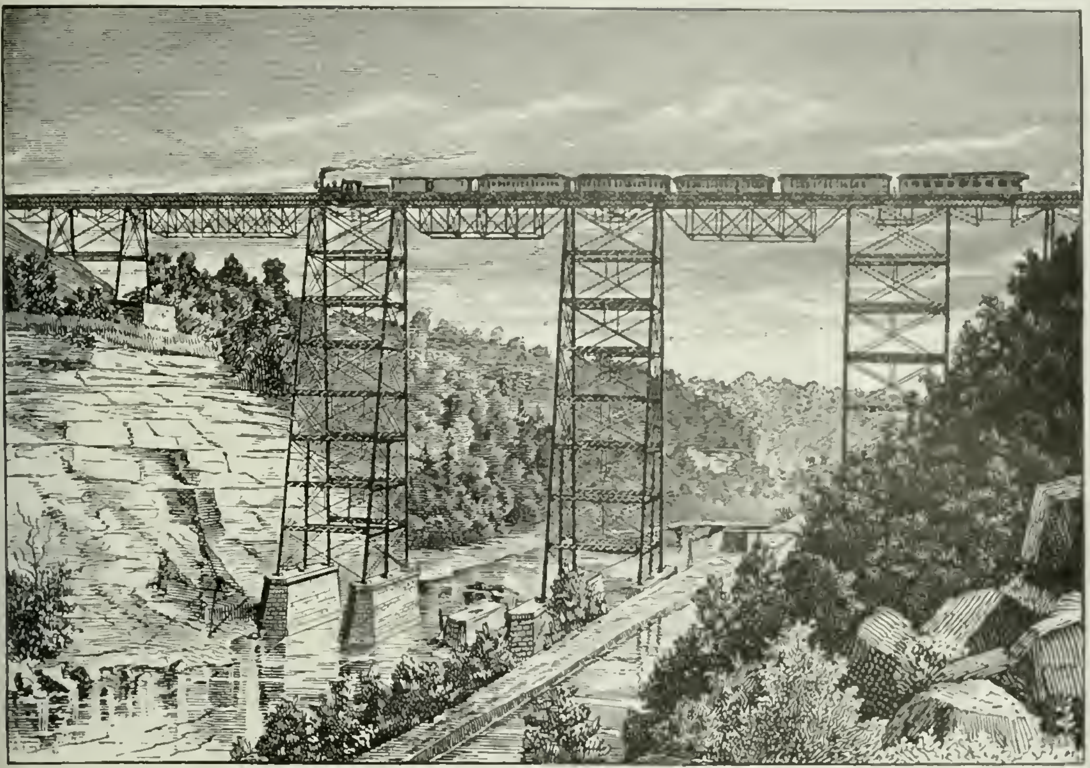

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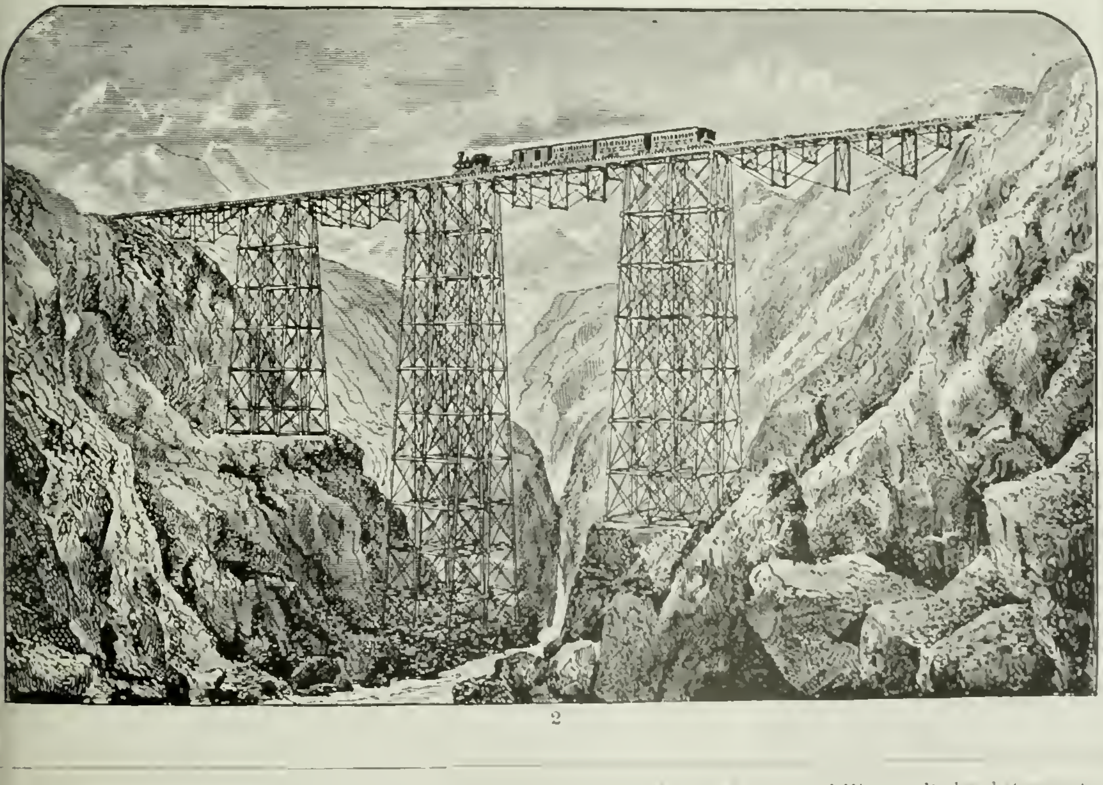

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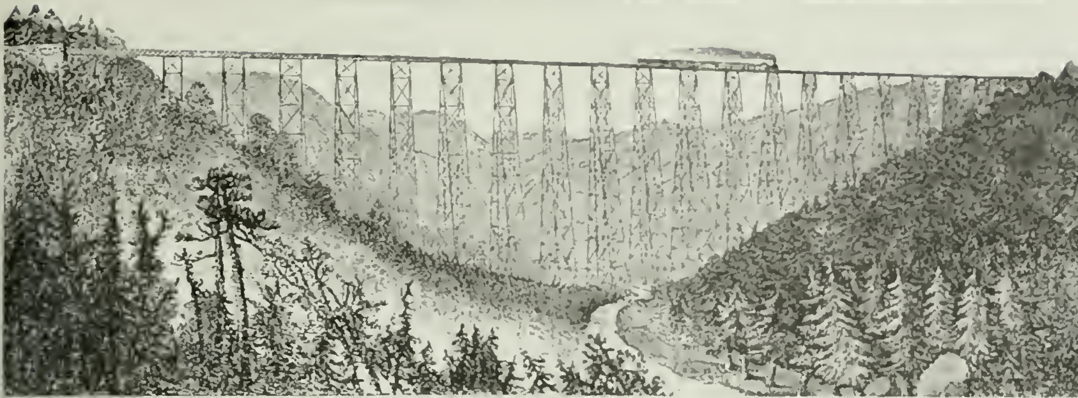

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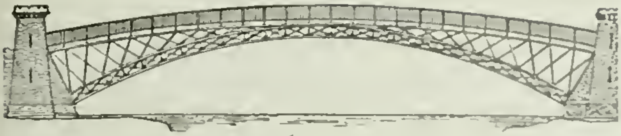

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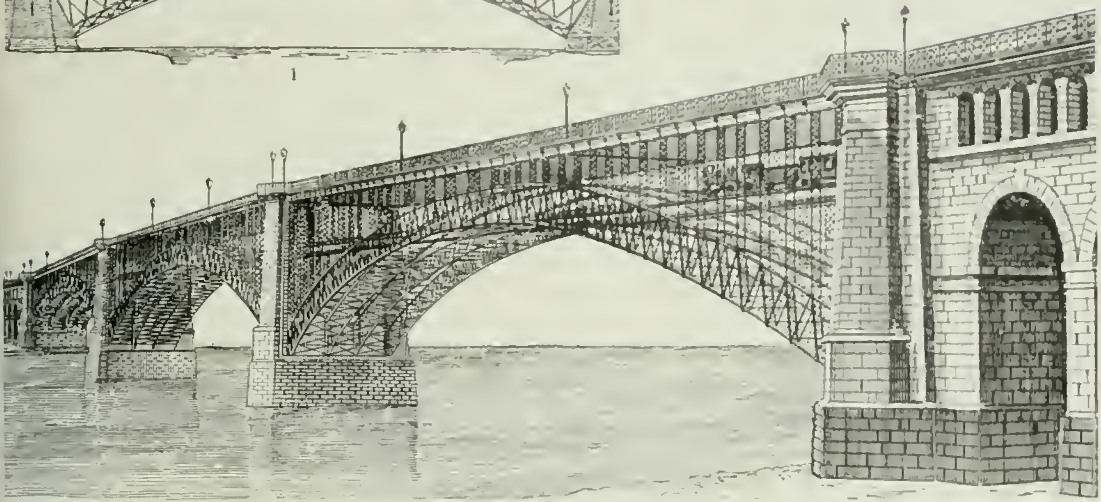

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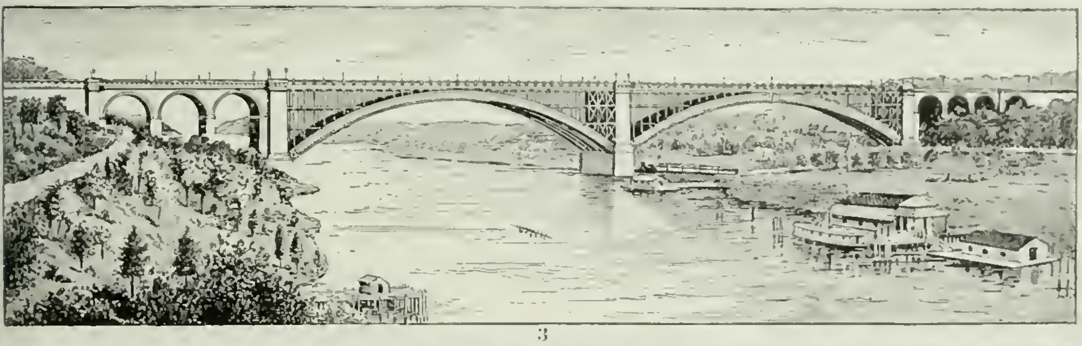

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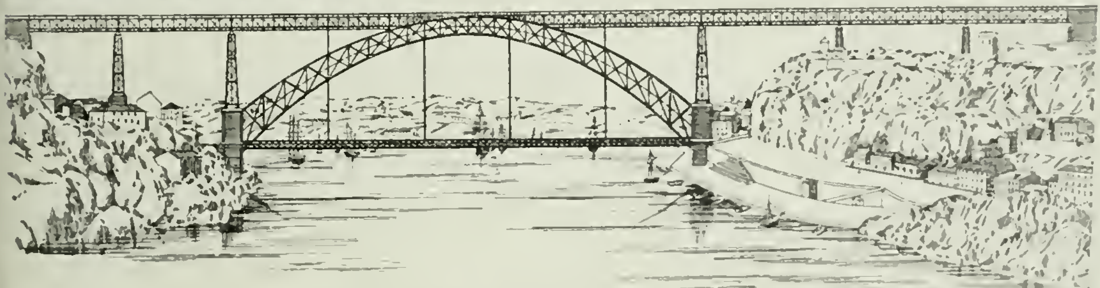

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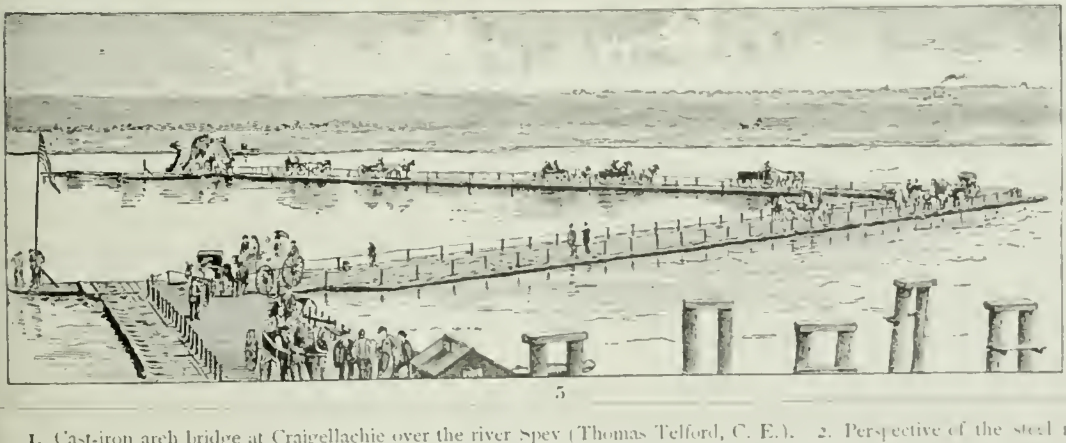

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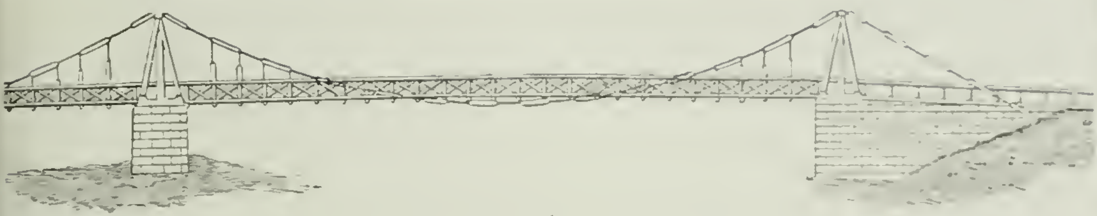

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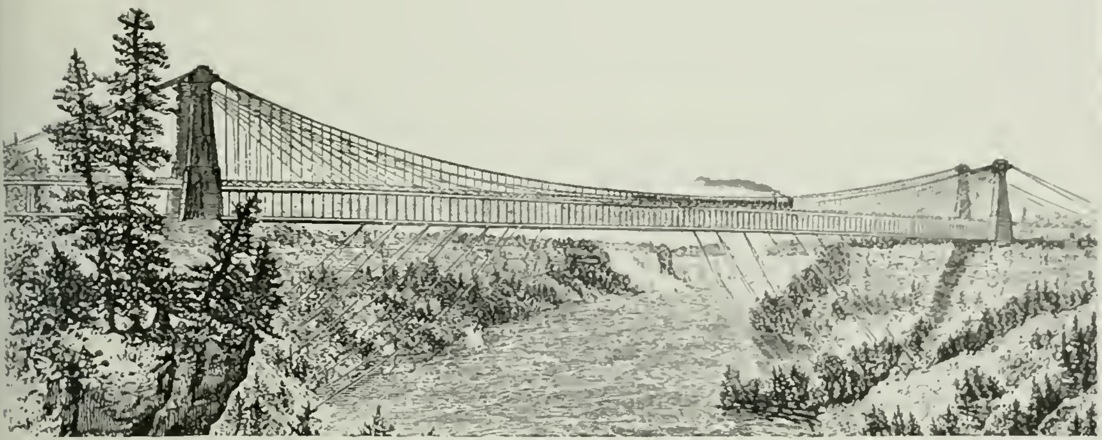

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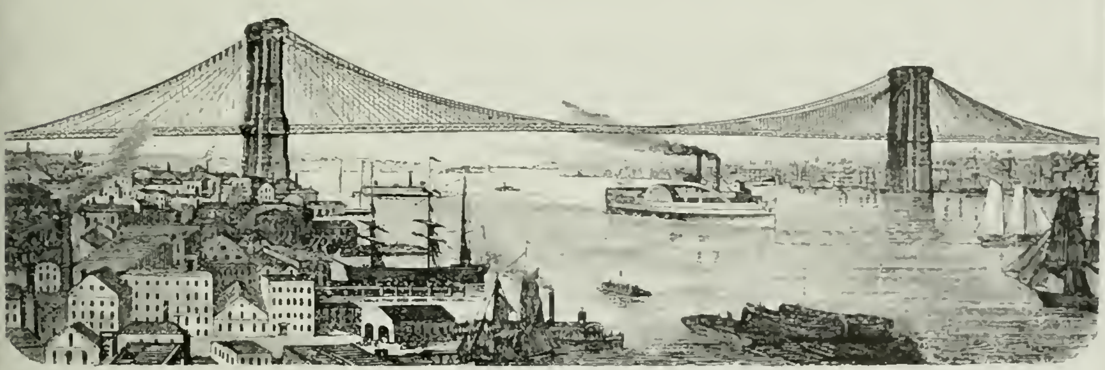

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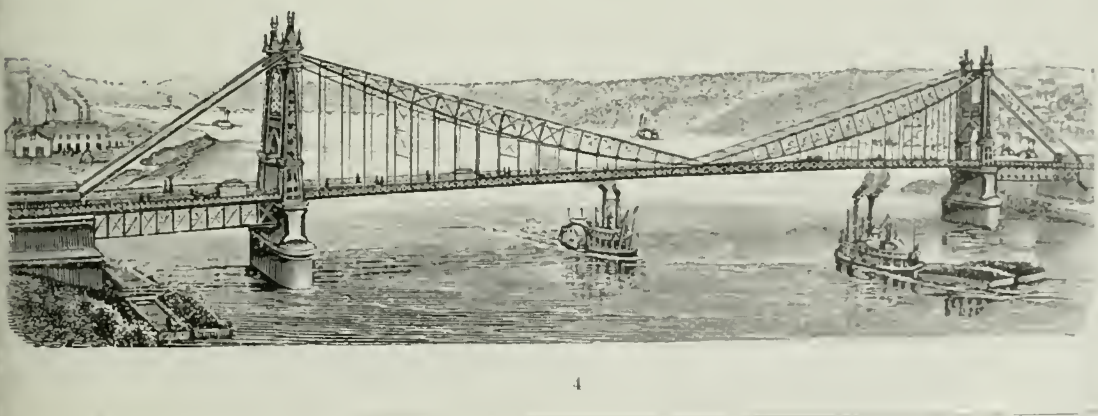

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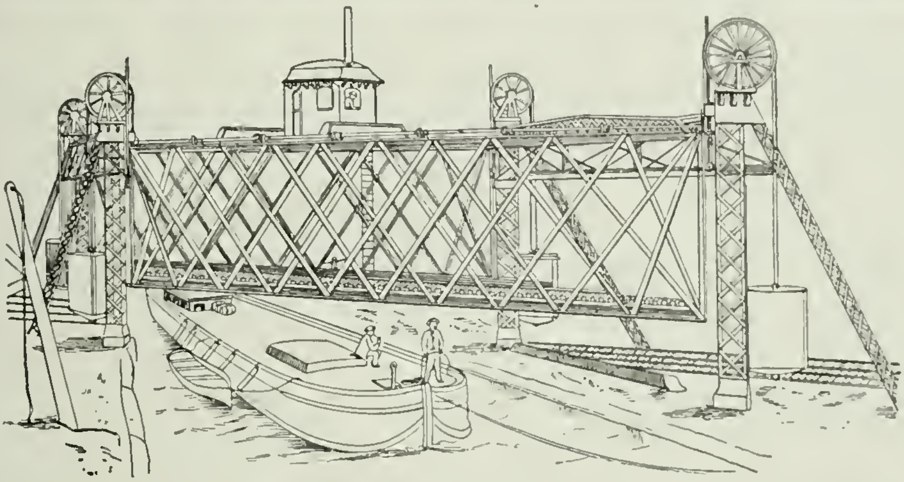

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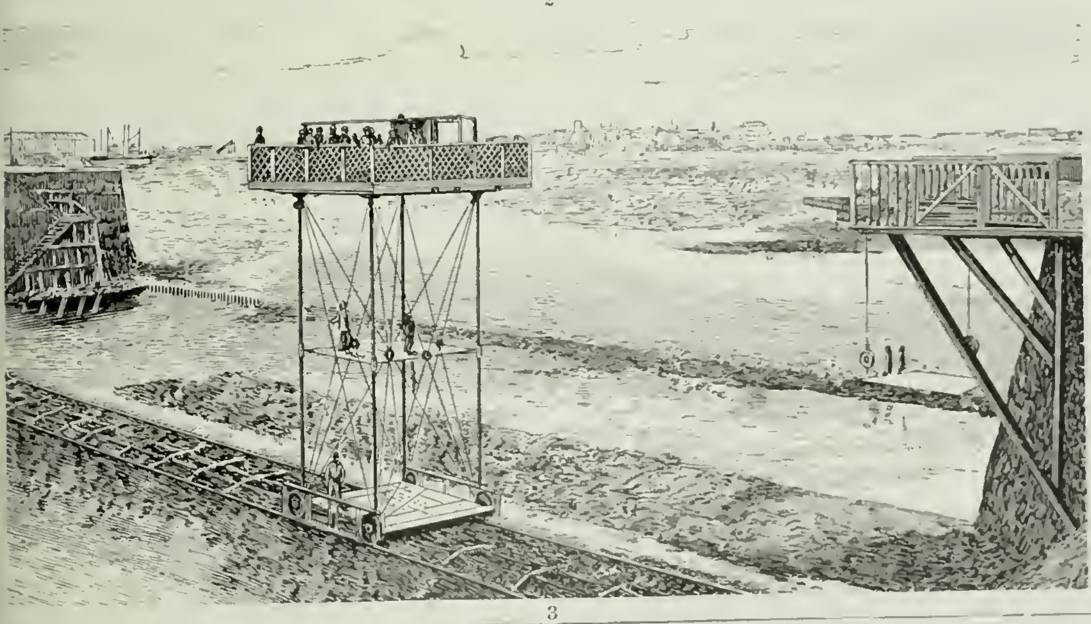

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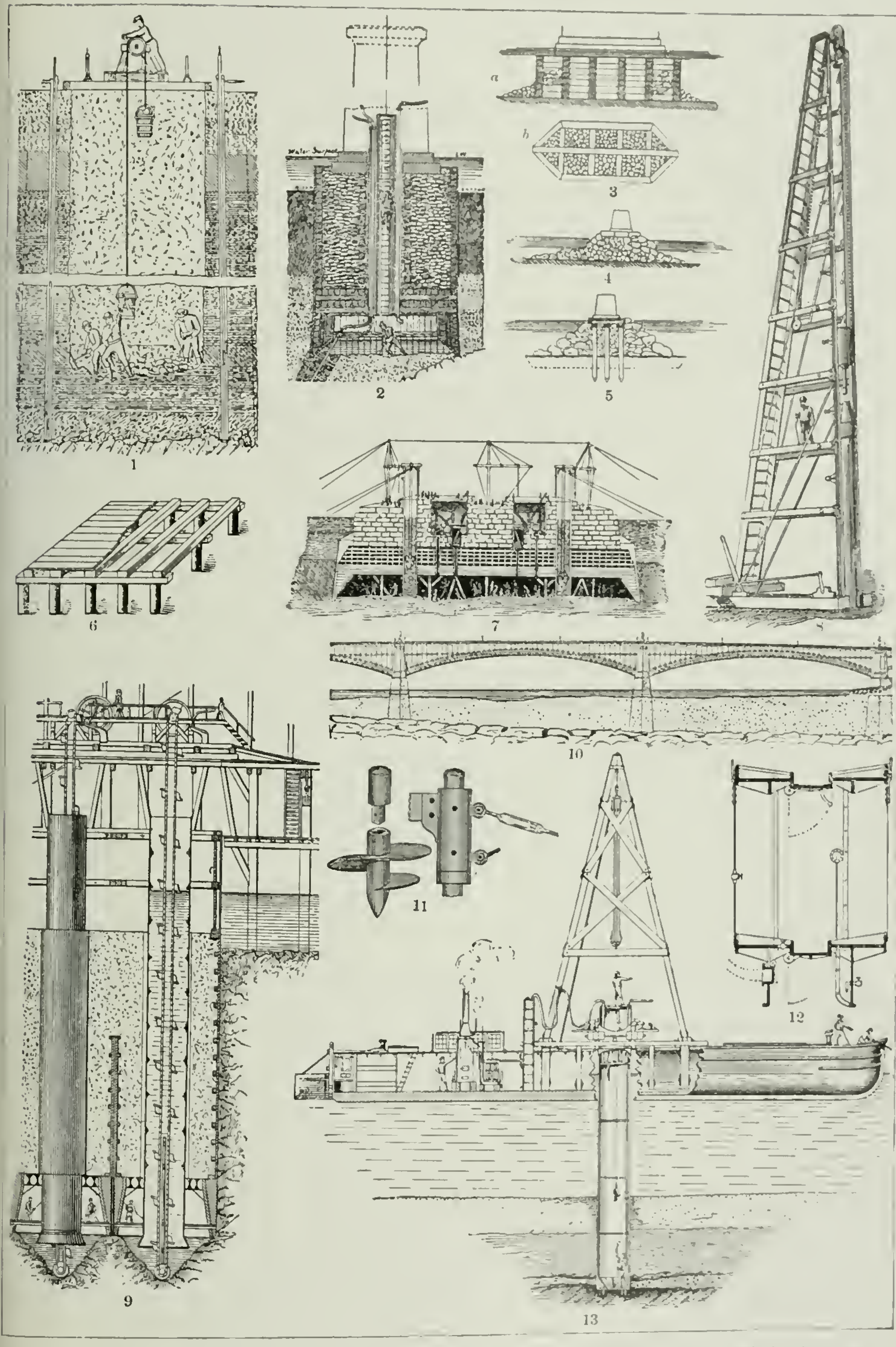

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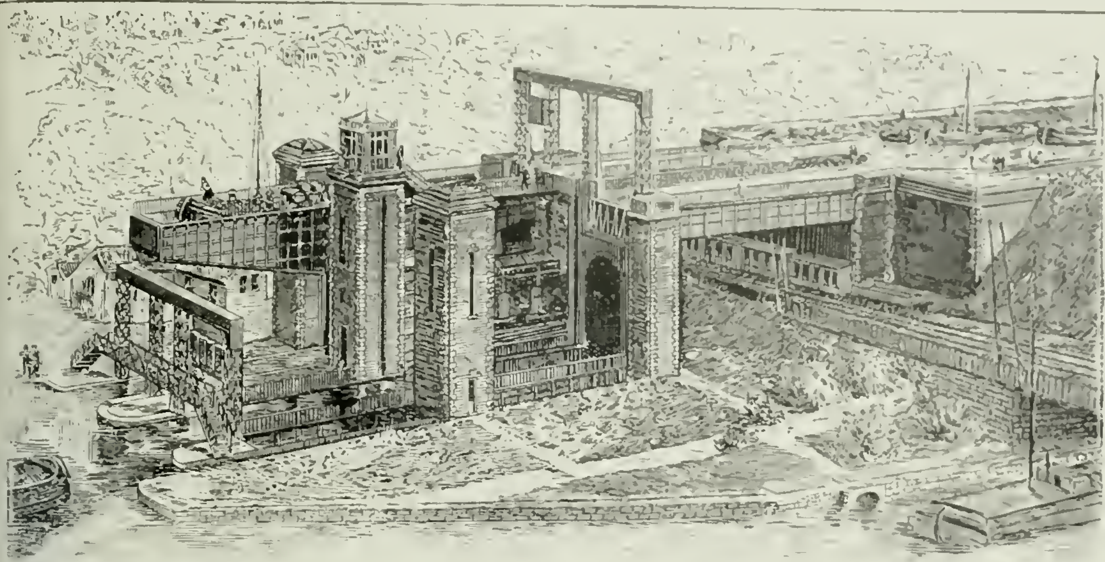

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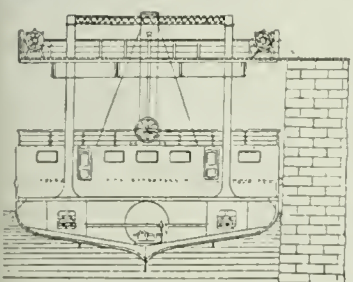

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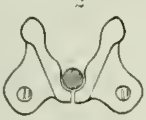

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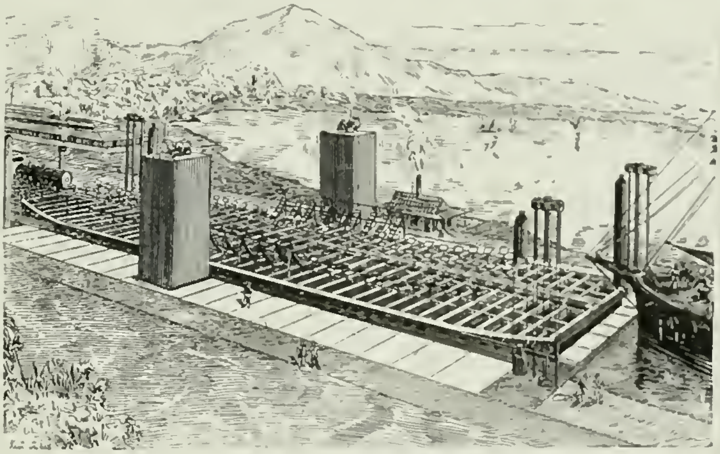

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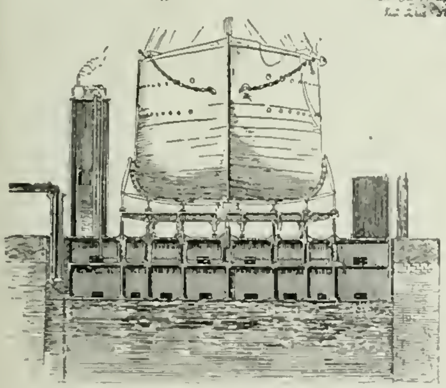

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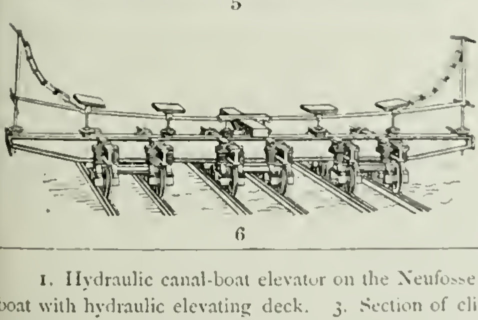

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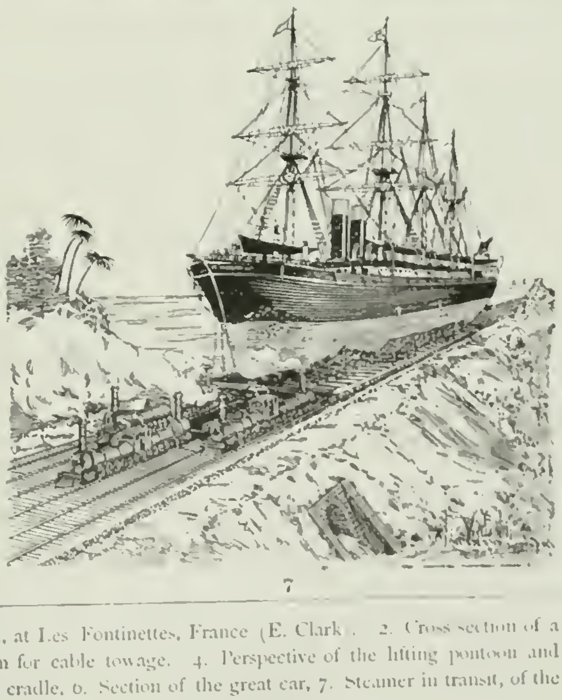

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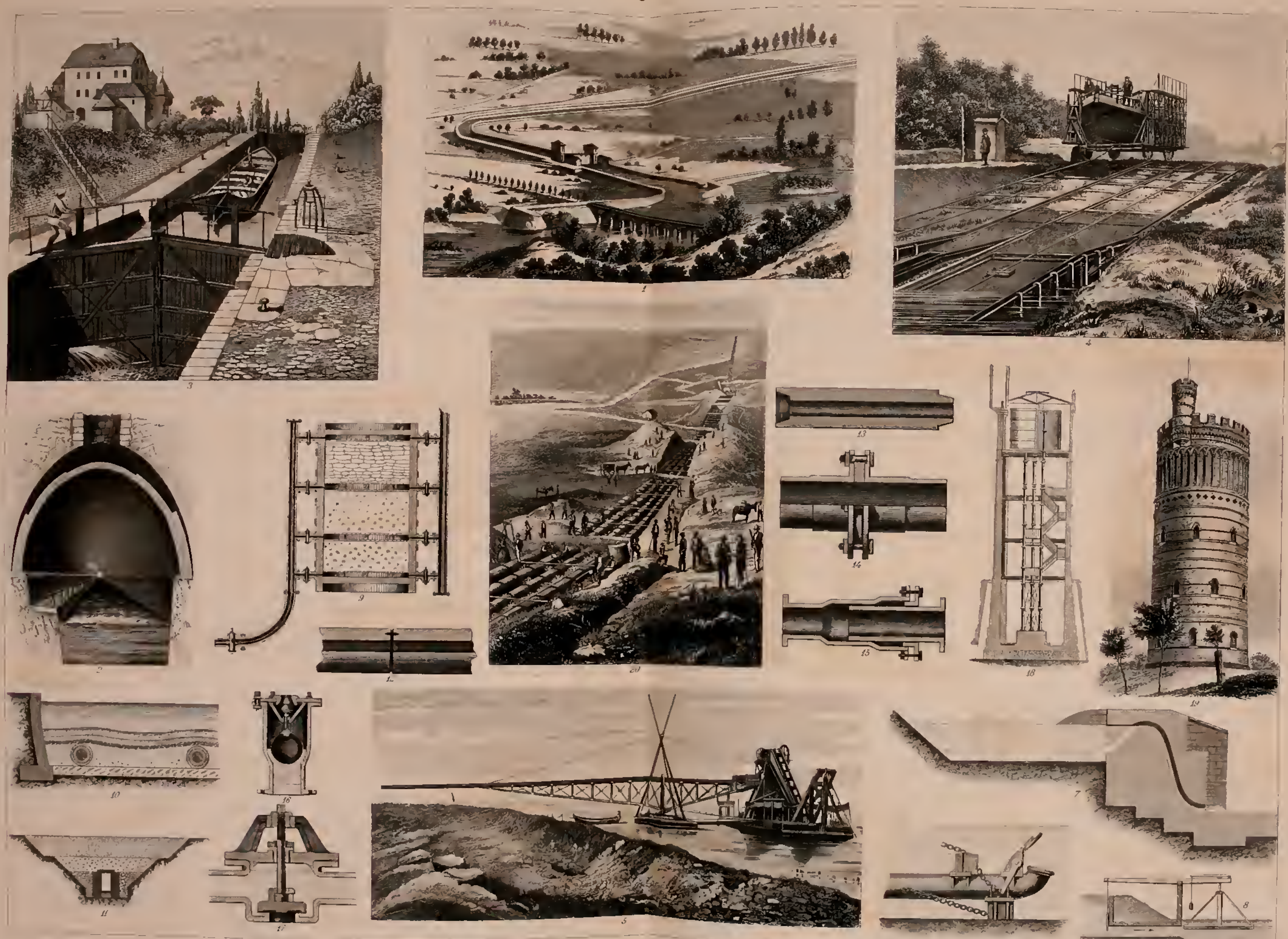

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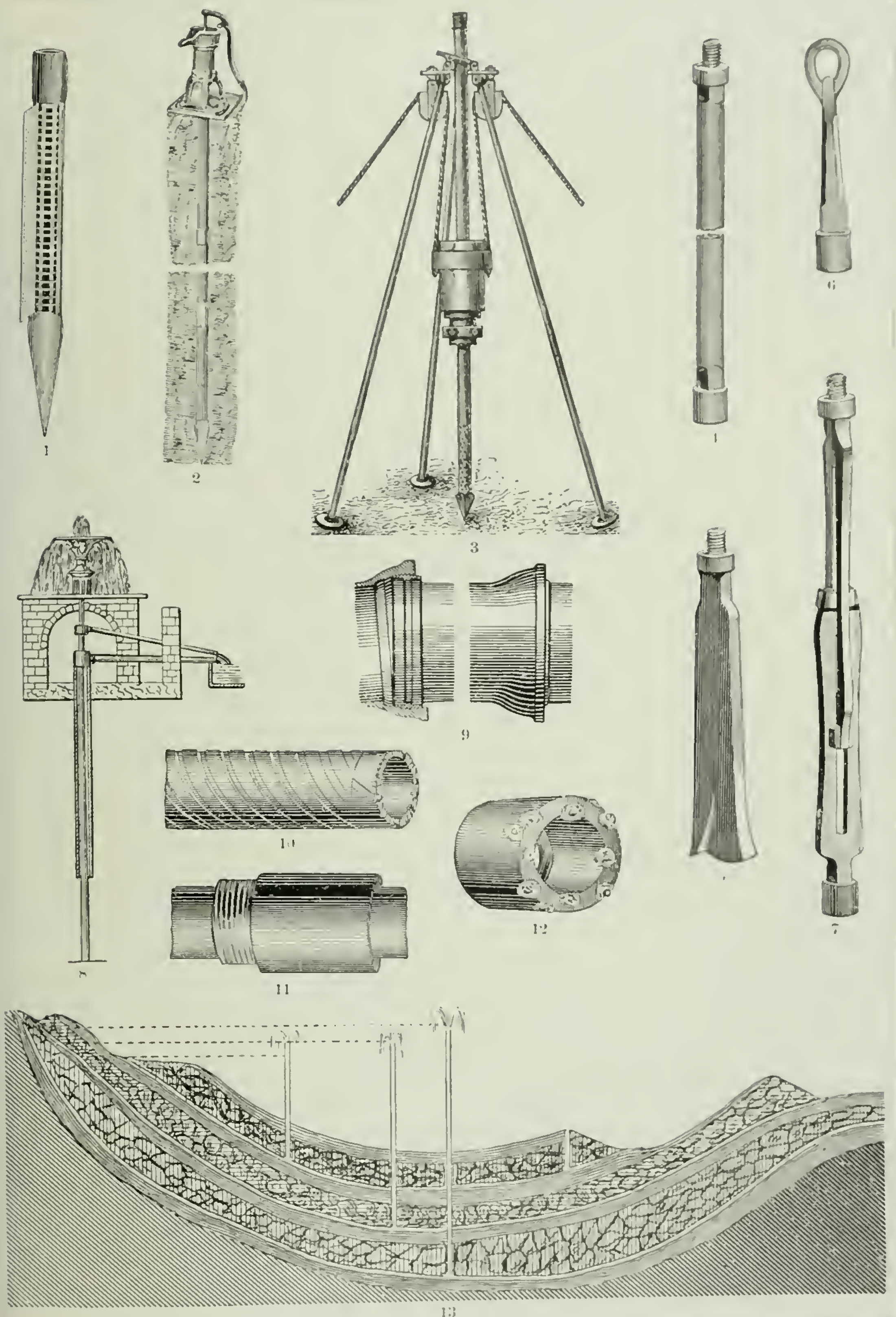

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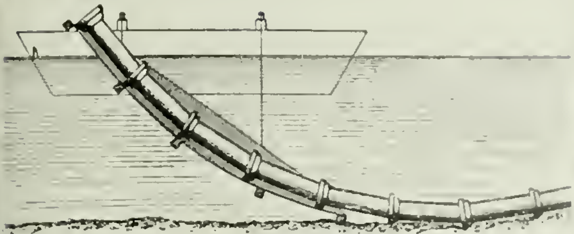

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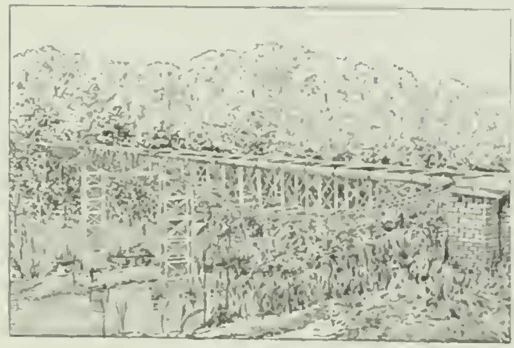

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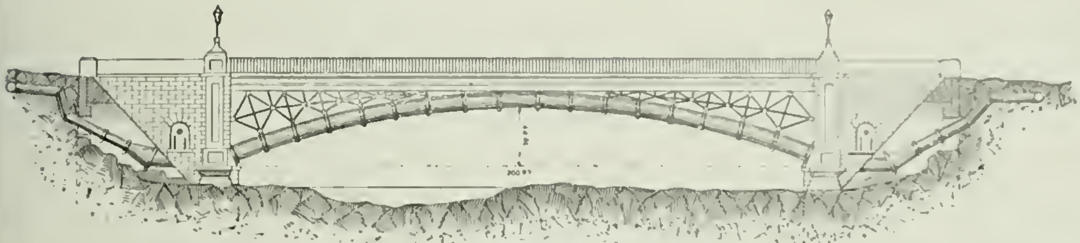

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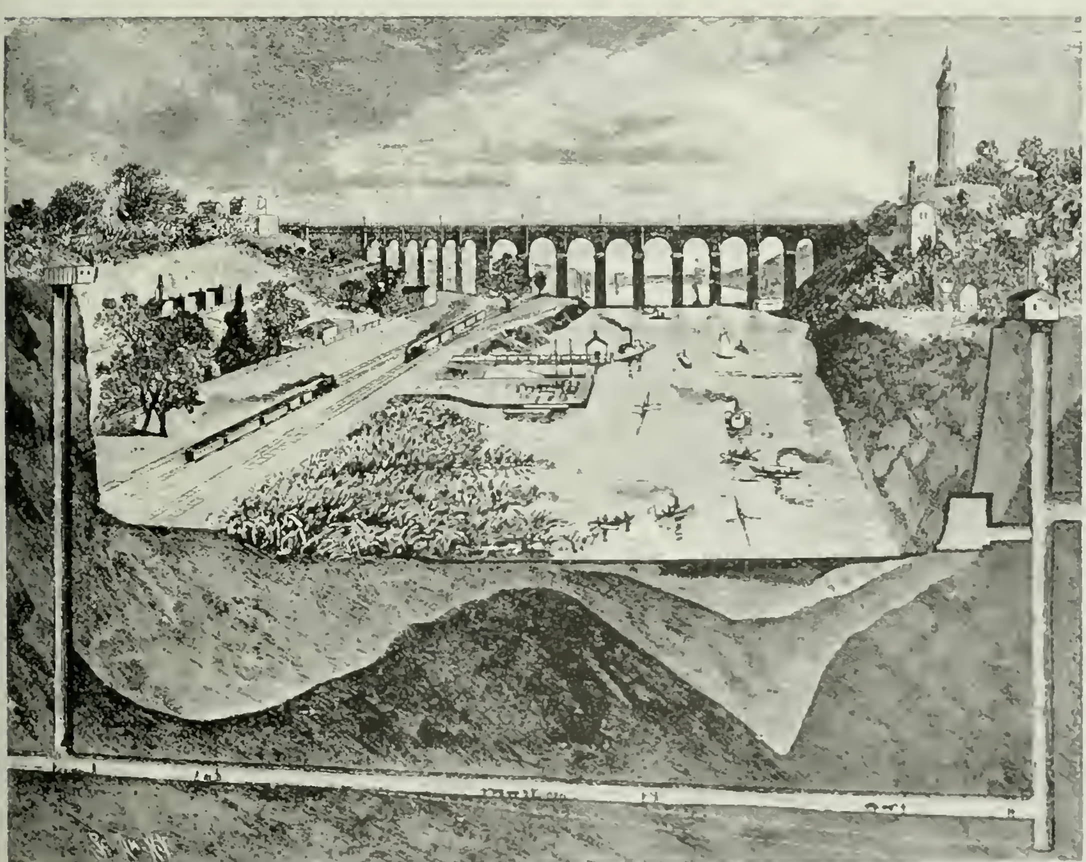

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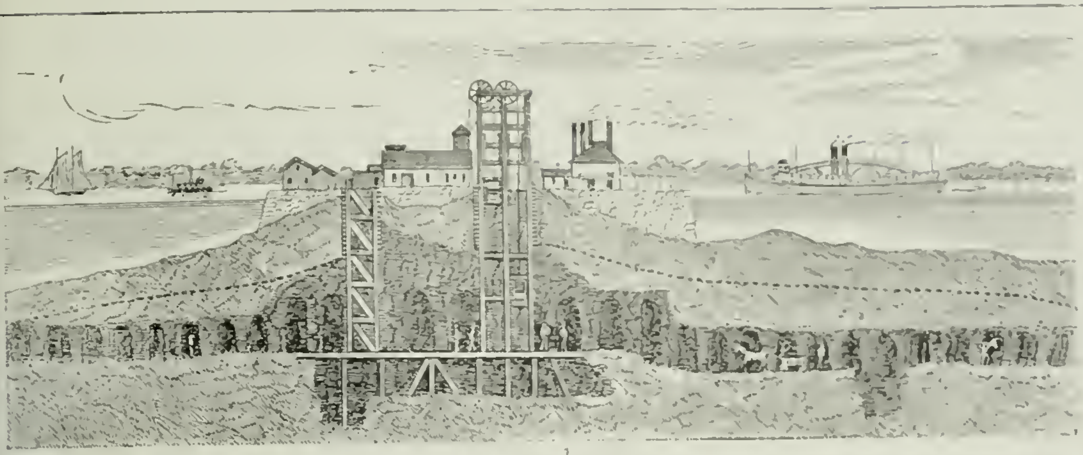

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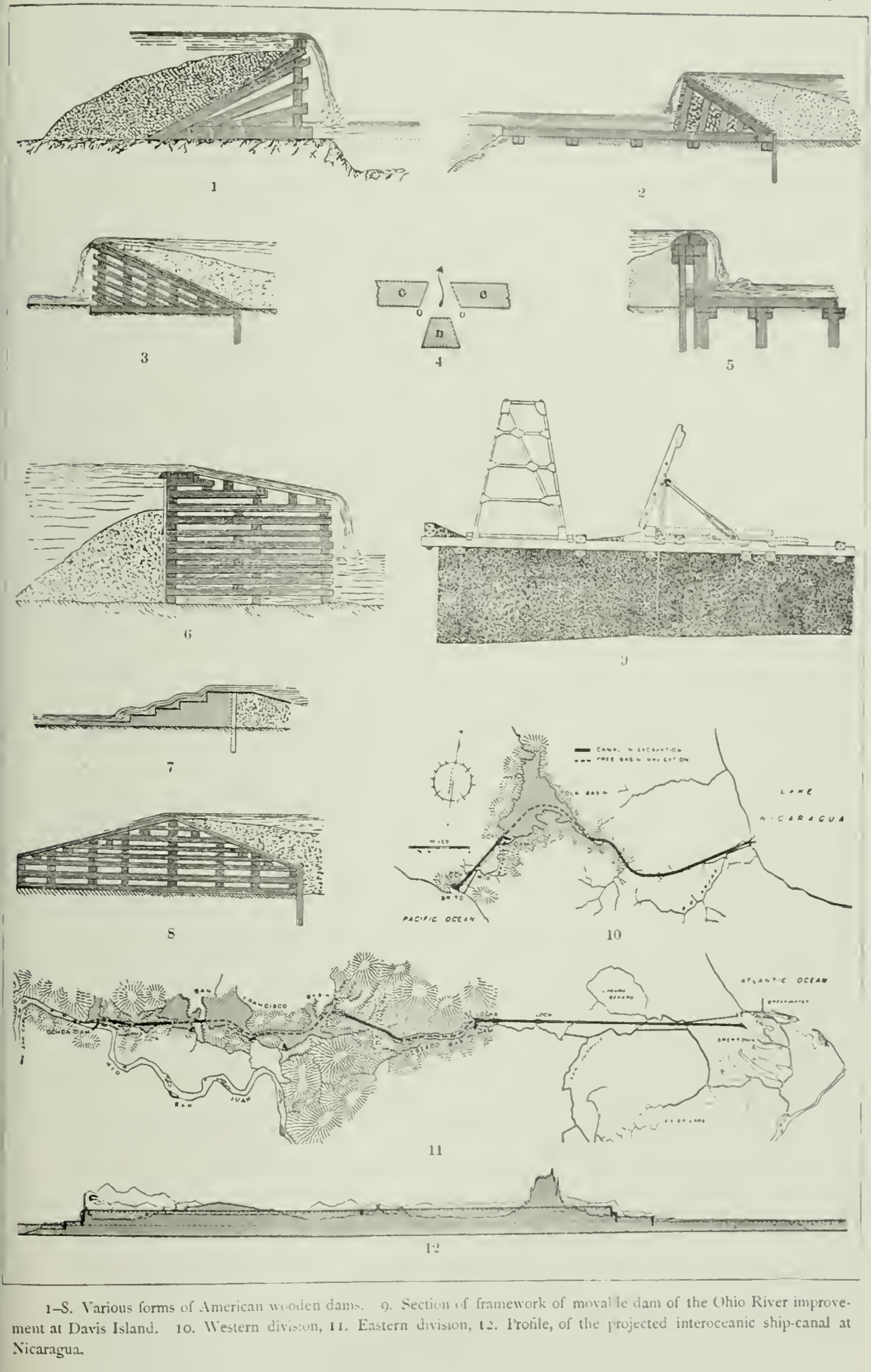

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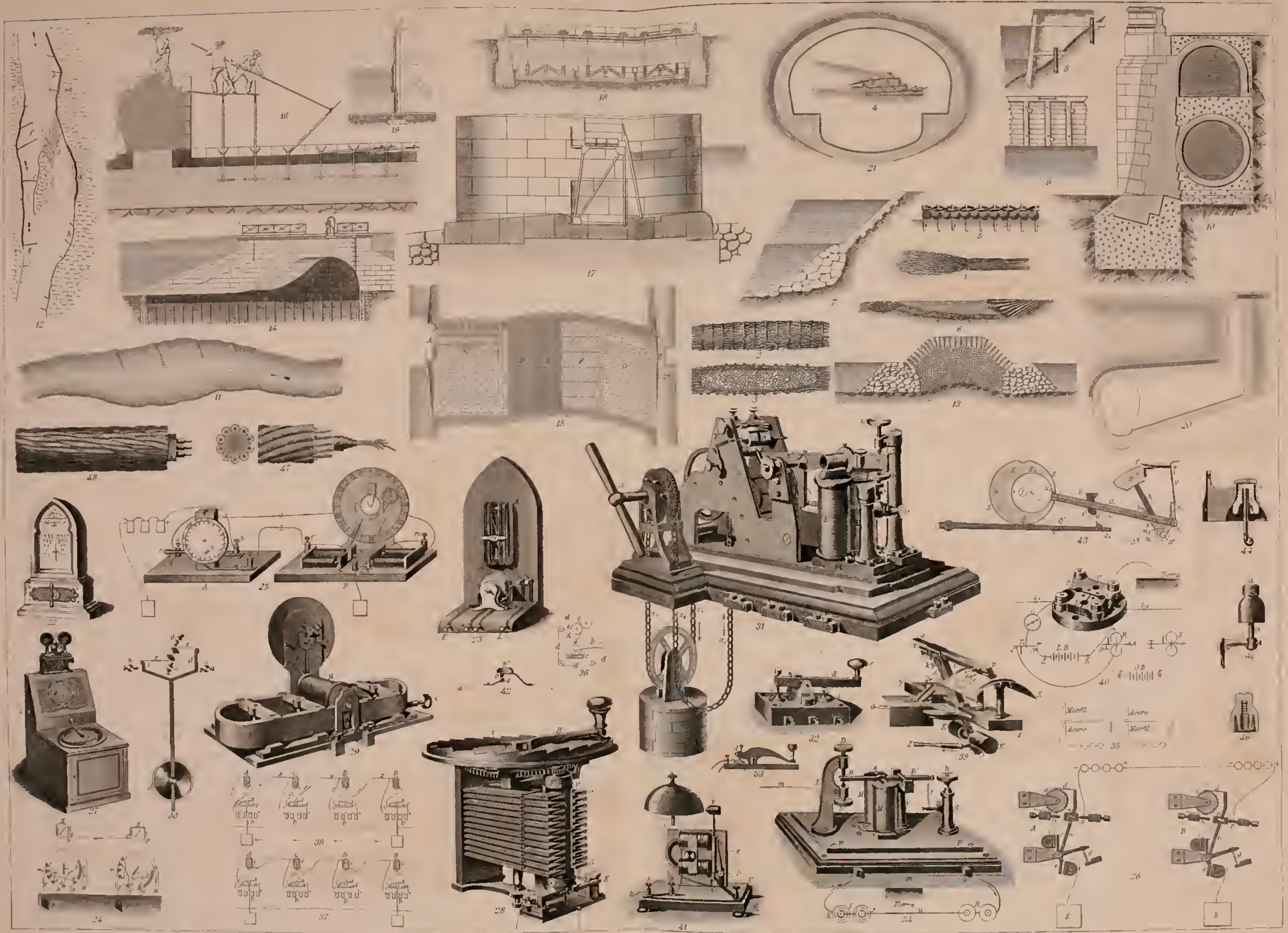

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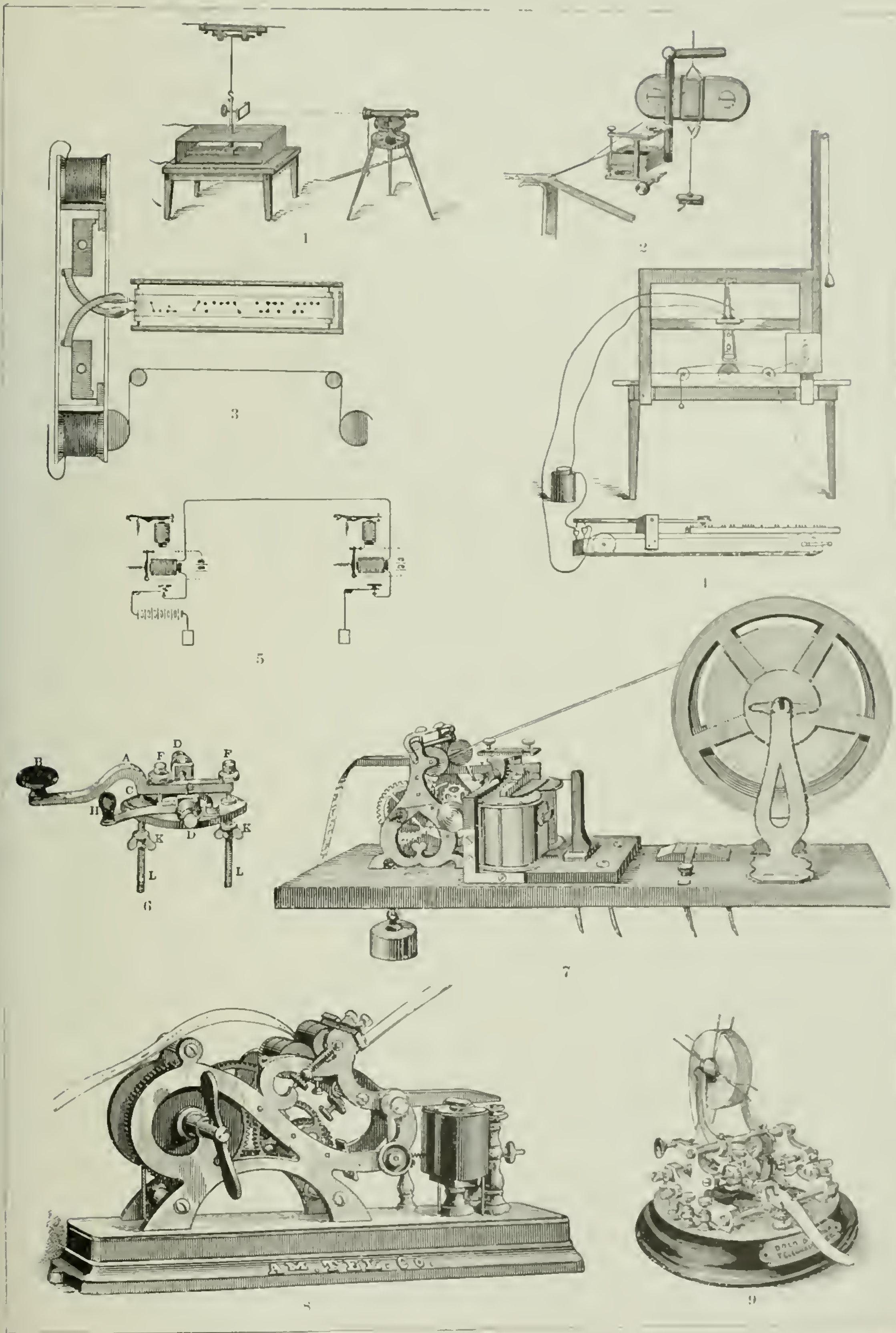

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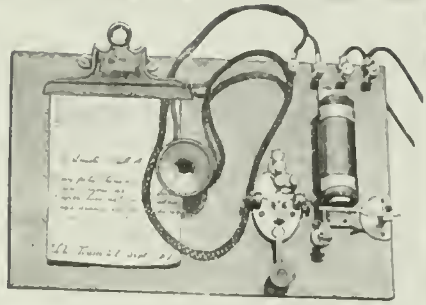

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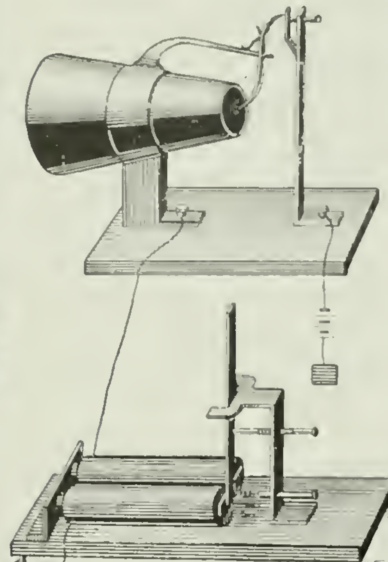

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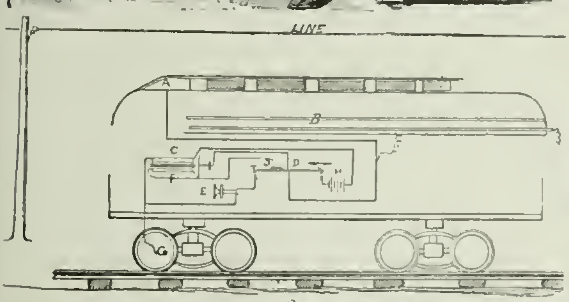

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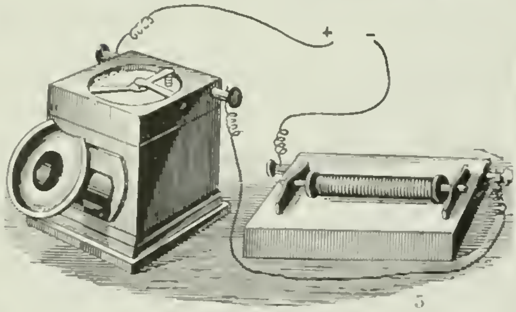

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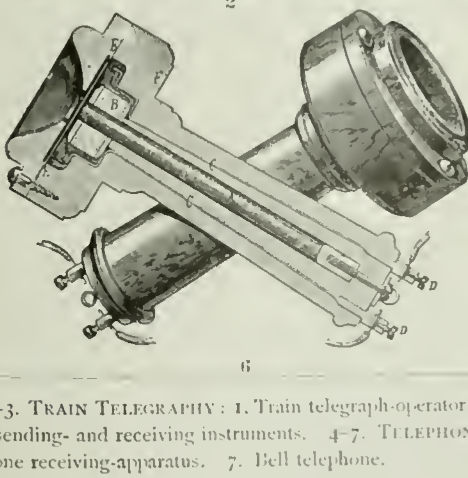

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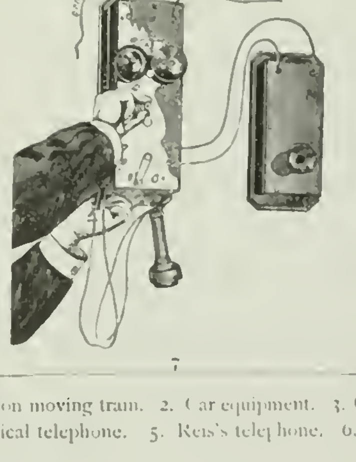

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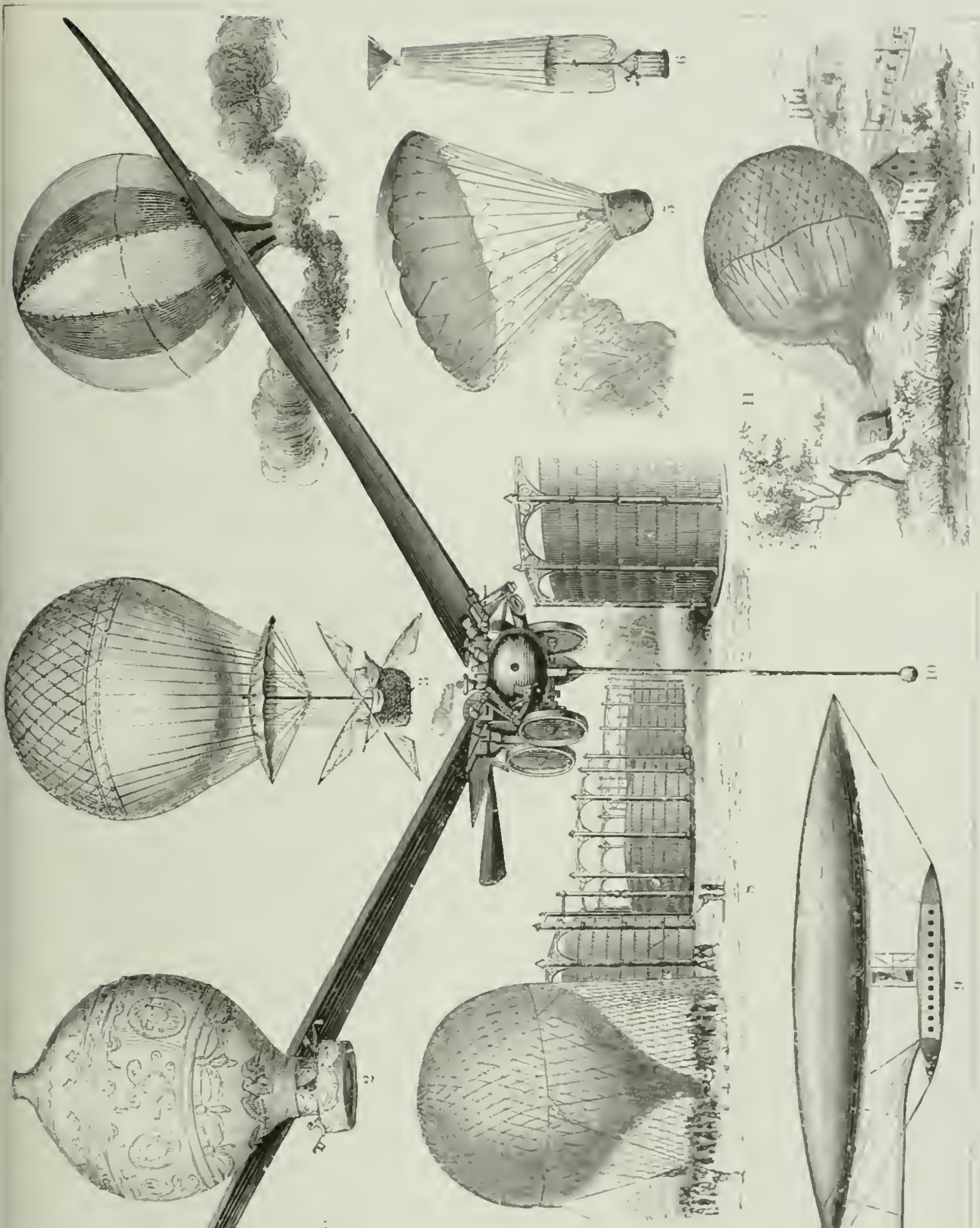

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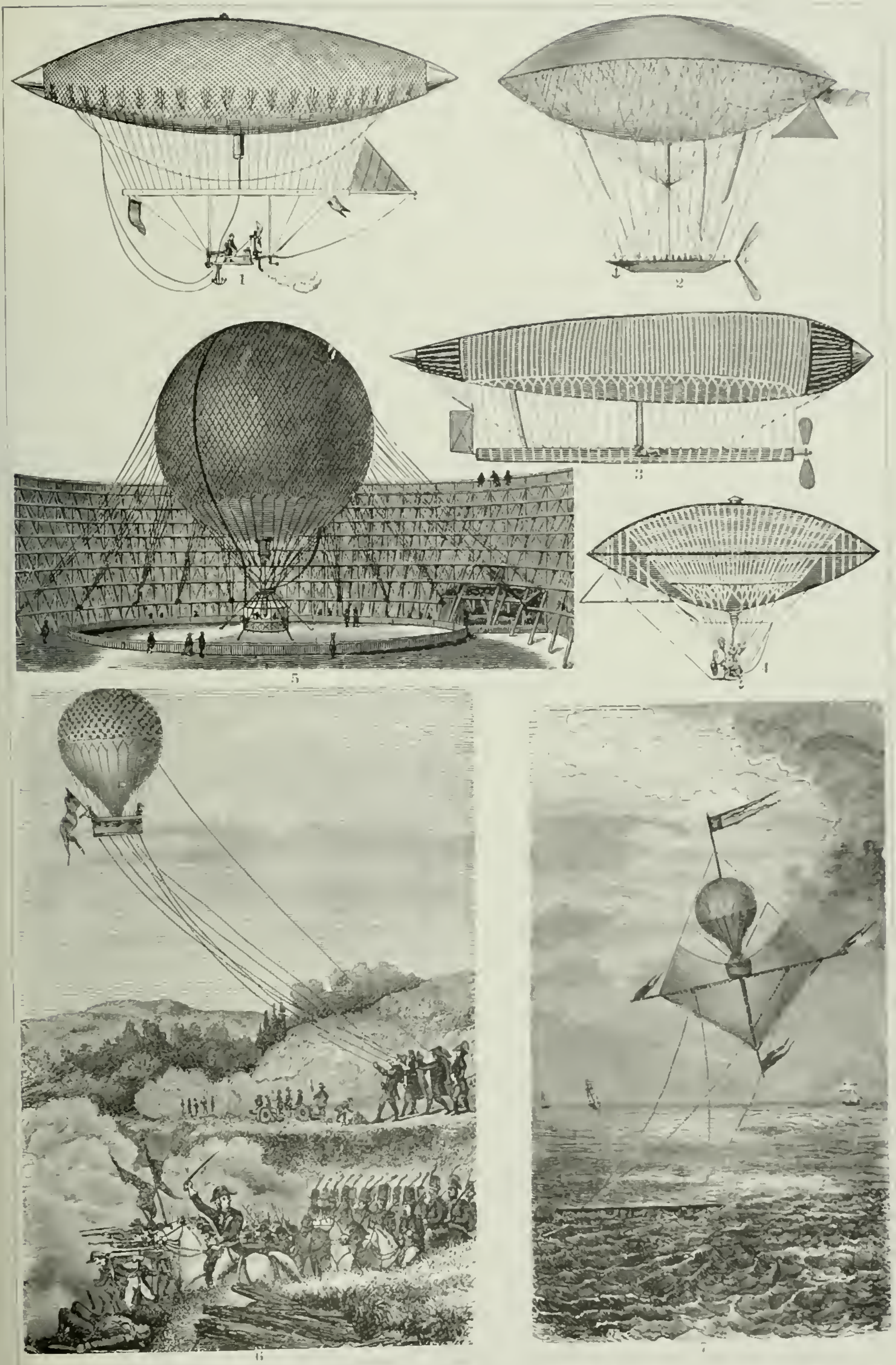

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